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Status of the Coastal Pacific Whiting Resource in 1990

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Martin W. Dorn, Richard D. Methot,
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and Mark E. Wilkins

Alaska Fisheries Science Center
National Marine Fisheries Service
National Oceanic and Atmospheric Administration
7600 Sand Point Way NE, BIN Cl5700
Seattle, WA 98115-0070

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National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road
Springfield, VA 22161

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ABSTRACT

This report evaluates the condition of the Pacific whiting (Merluccius productus) resource in 1990, examines alternative harvesting strategies, and develops a suggested acceptable biological catch (ABC) for 1991. The harvest of Pacific whiting in 1990 is expected to be 269,500 metric tons (t), down from a high of 309,000 t in 1989. The fishery continues to be supported by the strong 1980 and 1984 year classes. Assessment surveys in 1989 estimated the population biomass as 1.637 million t, a decline of 24% from estimates made in 1986. In the 1990 assessment, the stock synthesis model was used to estimate age-structured population abundance, past levels of female spawning biomass, and recruitment for the 1959-87 year classes. The assessment model was revised to include geographic structure; the parameters of a curve defining the annual migration of fish across the U.S.-Canada border were also estimated. Recruitment estimates and fishery selectivity coefficients from the stock synthesis model were used with an age-structured simulation model to estimate sustainable yield under different harvesting strategies and levels of risk. Several harvesting strategies are explored: a constant F strategy, a variable F strategy where fishing mortality for a particular year is proportional to the level of female spawning biomass, and a hybrid strategy that combines features of the other two policies. The hybrid strategy avoids the extreme variability in yield of the variable F strategy, yet protects the stock at low levels of female spawning biomass. Long-term average yield depends on the level of risk the managers are willing to accept. Risk is associated with the probability that the female spawning biomass will fall below a cautionary level of 457,000 t. Estimates of average yield ranged from 168,000 to 227,000 t for the constant F strategy and from 187,000 to 235,000 t for the hybrid strategy over a reasonable range of risk levels. When a hybrid fishing strategy is applied to the projected numbers at age in 1990, the potential yield is calculated to be 253,000 t for a moderate-risk strategy. The prospects in the immediate future for the Pacific whiting resource are for

stable or declining yields depending on the timing of the next strong year class.

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INTRODUCTION

Pacific whiting (<u>Merluccius productus</u>), also known as Pacific hake, is a migratory gadid distributed along the west coast of North America from Baja California to Queen Charlotte Sound. Adult Pacific whiting migrate north in spring and summer, feeding in the productive waters along the continental shelf and slope from northern California to Vancouver Island. In autumn, Pacific whiting migrate south to spawning areas from Point Conception, (Fig. 1), to Baja California (Bailey et al. 1982). The midwater trawl fishery for Pacific whiting, operating in both U.S. and Canadian waters, targets on dense feeding aggregations of fish that occur along the shelf break from April to November.

Francis and Hollowed (1985) summarize the history of the coastal fishery for Pacific whiting as follows. A small domestic fishery for whiting has existed since at least 1879. The Soviet Union initiated a foreign fishery for this species in 1966. Between 1973 and 1976, Poland, the Federal Republic of Germany (West Germany), the former German Democratic Republic (East Germany), and Bulgaria entered the fishery. The estimated catches of Pacific whiting ranged from 118,000 to 238,000 metric tons (t) during this period of expansion (Table 1). Catches peaked in 1976 and were subsequently reduced, due primarily to restrictions on foreign effort imposed after implementation of the Magnuson Fisheries Conservation and Management Act (MFCMA) of 1976.

A joint venture fishery for Pacific whiting started in 1978 between foreign nations and the United States. In recent years (1980-88), this fishery, involving predominately Soviet and Polish processing vessels, has accounted for an increasing percentage of the whiting catch in the U.S. and Canadian management zones. At the same time, the foreign fishery has declined in importance (Table 1). In 1989, there was no foreign fishery for Pacific whiting in U.S. waters. In Canadian waters, the foreign fishery has also declined.

Combined U.S. and Canadian catches were below the recommended levels during the period from 1977 to 1986. With the domestication of the U.S. fisheries in the Gulf of Alaska and Bering Sea, foreign interest in Pacific,

whiting has increased in the last few years. In 1987, the combined quota for the United States and Canada exceeded the acceptable biological catch (ABC) for the first time. The coastal Pacific whiting resource is now fully utilized, and in 1989 the combined U.S. and Canadian catch was 309,000 t--the largest yield since the inception of large-scale exploitation in 1966.

In 1990, research on the biology and management of the coastal Pacific whiting population at the Alaska Fisheries Science Center (AFSC) focused on 1) investigation of the migratory characteristics of the population within the stock synthesis framework; 2) analysis of the results of the 1989 west coast acoustic and bottom trawl surveys, including reestimation of the natural mortality rate; 3) examination of seasonal variability in the Pacific whiting length-weight relationship to determine the impact of a compressed fishery on the sustainable yield; and 4) development and analysis of a long-term allocation plan to split the yield between the U.S. and Canadian fisheries for Pacific whiting.

CATCH ATTRIBUTES

Catch-at-Age Estimates

Estimates of catch at age for the joint venture fishery in 1989 were calculated using the procedure developed by Kimura (1989). With this method, the yield for a given stratum is distributed by age by applying the length frequency data to age-length and weight-length keys compiled for that stratum. A background age-length key was used to fill in the gaps in the keys compiled for each stratum. The following three spatial strata were used: 1) the EUR region, the area from lat. 39°00'N to lat. 43°00'N, which contained the entire Eureka International North Pacific Fisheries Commission (INPFC) region and a portion of the Monterey INPFC region; 2) the southern Columbia (SCOL) region, the area from lat. 43°00'N to Cape Falcon (lat. 45°46'N) in the Columbia INPFC region; and 3) the Vancouver-North Columbia region (VNC), the area from Cape Falcon to the U.S.-Canada border, which included the northern part of the Columbia INPFC region and the U.S. portion of the Vancouver INPFC region

(Fig. 1). Table 2 contains the estimated U.S. fishery catch at age for 1978-89 (Jerald Berger, U.S. Foreign Fishery Observer Program, Alaska Fisheries Science Center, National Marine Fisheries Service, NOAA, 7600 Sand Point Way NE, BIN C15700, Seattle, WA 98115. Pers. commun., May 1990), and the Canadian catch at age for the corresponding years (Mark Saunders, Pacific Biological Station, Department of Fisheries and Oceans, Nanaimo, B.C. V9R 5K6. Pers. commun., May 1990).

Spatial and Temporal Characteristics of the Catch

Figure 2 shows the spatial distribution of mid-water trawls in the 1989 U.S. joint venture fishery for Pacific whiting. In April, the fishery was concentrated in the southern portion of the Columbia INPFC region and in the Eureka INPFC region. In May, fishing effort was widely distributed from the Eureka INPFC region north to the international boundary. In June, the area of fishing activity contracted slightly, but remained widely distributed in patches along the coast. Fishing activity tended to be concentrated near the 200 m isobath, which marks the edge of the continental shelf. In addition, there was an area of intense fishing activity inshore of Heceta Bank located near lat. 40°00'N.

The regional characteristics of the catch at age are shown in Figure 3. As has been found in the past, older fish become proportionately more abundant in the catch in the more northern areas. In 1989, the fishery operated further south than it had in previous years, with most of the catch coming from the Eureka and south Columbia regions. Figure 3 also documents the lack of strong recruitment to the fishery since the 1984 year class.

As foreign interest in the Pacific whiting resource has increased, the joint venture fishery has undergone a rapid evolution. In 1990, the U.S. fishery, which formerly extended from late April to early November, was over by 23 June, lasting less than 3 months. Participation in the fishery by processing vessels of different nationalities has also changed. An increasing percentage of Pacific whiting is being delivered to high capacity surimi processors from Japan instead of the traditional Soviet and Polish vessels

(Fig 4). The Pacific whiting joint venture fishery is currently managed under
the "Olympic system," which does not allocate between the various
nationalities of the processing vessels nor between the joint venture
companies. Under this system, increasing interest in the Pacific whiting
resource will further compress the fishery and will give the advantage to
processing vessels and catcher boats that can quickly process large volumes of
fish.

The domestic fishery for Pacific whiting has been concentrated in the
Eureka INPFC region in northern California, where several processing plants
specialize in Pacific whiting. Although this fishery has increased steadily
since 1986, it remains small relative to the total catch (Fig. 4).

GROWTH

Trends in Length at Age

Because changes in size have a direct effect on the available yield,
growth trends need to be examined to adequately assess the productivity of the
resource. Length-at-age estimates for Pacific whiting in the U.S. joint
venture fishery in 1989 were compiled using the procedure described in Dorn
and Methot (1990). Table 3 contains the 1989 length at age in the U.S. joint
venture fishery (Jerald Berger, Pers. commun., May 1990) and Canadian joint
venture fishery (Mark Saunders, Pers. commun., May 1990). Also given in
Table 3 are the a and b coefficients of an exponential length-weight
relationship of the form $w = a \, 1^{b}$ (Ricker 1975), estimated with nonlinear
regression. Figure 5 shows mean length at age in the U.S. fishery for the
months April-June for the years 1978-89. The months April-June were selected
so that length at age for earlier years could be compared to 1989, when the
fishery ended earlier than in previous years. A decline in mean length for
most ages is clearly evident, with the most substantial decline occurring from
1982 to 1988. Size at age for the younger fish has been stable in recent
years, A more direct assessment of current growth trends is made possible by
comparing the growth trajectory of the strong 1980 and 1984 year classes,

which have dominated the catches in recent years (Fig. 6). The 1984 year class was larger at age than the 1980 year class until 1989, when they were approximately the same size.

Two independent papers on the growth trends of Pacific whiting have recently been completed (Dorn 1990, Smith et al. 1990). These papers analyze the length at age in the U.S. and Canadian fisheries respectively. The analysis of the U.S. fishery data detected significant correlations between annual growth and two environmental factors: sea surface temperature and adult biomass. Reductions in annual growth were associated with both elevated summer sea surface temperatures and increases in adult biomass. The analysis of the Canadian fishery data found that the decline in the mean length at age in the Canadian catch since 1976 was significantly correlated with an increase in adult biomass and an increase in exploitation due to the Canadian fishery. Oceanographic factors (sea level height, sea surface temperature, and salinity) also had significant effects on length at age. Influence of oceanographic factors on. the migration of different sized individuals into the Canadian zone was proposed to account for this correlation.

Effect of a Shortened Fishery on Sustainable Yield

Since spring and summer are periods of rapid growth for Pacific whiting, an early fishery, as occurred in 1989 and 1990, could affect sustainable yield from the resource. To investigate this possibility we analyzed seasonal changes in the length-weight relationship using the length-weight data from 1988, the last year that the fishery extended through the summer and into fall. A factorial analysis of variance was used with the logarithm of weight as a dependent variable and the logarithm of length as a covariate. The factors were area, time period, age, and sex. See Reish et al. (1985) for an equivalent analysis of the Atlantic menhaden (_Brevoortia tyrannus_). The model is $\log_e(\text{weight}) = a + b \log_e(\text{length})$ --the log transform of the usual length-weight relationship. The scale parameter, a, is the sum of the terms that

enter the model linearly, while the power parameter, b, is the sum of the interaction terms between the factors and $\log_e$(length).

Table 4 presents the analysis, and Table 5 gives the parameter estimates. All factors were highly significant (p < 0.01) except region, indicating that there is little geographic variability in the length-weight relationship. The intercept coefficient and the coefficient for $\log_e$(length) in Table 5 apply to the length-weight relationship of an age-1 male in the Eureka and Monterey INPFC regions in the early time period. The coefficients for each linear factor level are the estimated difference in the scale parameter in the length-weight relationship between individuals in that factor level and those individuals with the intercept characteristic. The coefficients for each interaction factor level are the estimated difference in the power parameter in the length-weight relationship between individuals in that factor level and those individuals with the intercept characteristic. The parameter estimates in Table 5 are difficult to interpret because the scale parameter and the power parameter are highly correlated.. However, using these coefficients to predict weight for a given length, the following conclusions can be drawn: 1) females are slightly heavier at length than the males, 2) weight at length decreases with the age of the fish, and 3) weight at length increases substantially during the fishing season.

Figure 7 shows the mean weight at age of fish in the U.S. fishery for the early, middle, and late time periods. These weights were calculated by obtaining mean length by time period and age for the years 1978-89. A simplified ANOVA was used to estimate scale and power coefficients for time period and age alone. These coefficients were used to convert the lengths to weights. The estimated weights were multiplied by the correction factor, $e^{0'/2}$, to adjust for the bias that arises when regression coefficients estimated using log-transformed data are used in predictive equations with the untransformed data (Beauchamp and Olson 1973). The LOWESS scatterplot smoother (Cleveland 1979) was used to smooth the weight-at-age data. Weight

at age increases an average of 15.1% from the early to the middle time period, and there is a further 8.3% increase in weight from the middle to the late time period. The percent increase in weight is largest for the younger fish and is less for the older fish.

To examine the effect of the seasonal exploitation pattern on sustainable yield, we configured a yield-per-recruit model to describe the seasonal patternof the Pacific whiting fishery. The smoothed seasonal weights at age in Figure 7 were used in the model. Prior to 1989, 27.9% of the catch in numbers came from the early period (April-June), 47.9% from the middle period (July-August), and 24.7% from the late period (Sept.-Nov.). This exploitation pattern was contrasted with the exploitation pattern that occurred in 1989, when the fishery was over by the end of June. In the early fishery alternative, sustainable yield for the U.S. fishery declined by 6.0%, or approximately 9,300 t for a mean recruitment of 1.23 billion fish (1960-89 average). If the U.S. fishery operated only during the months of July and August, the sustainable yield would increase by 7.4%, or approximately 12,000 t, over the current April-June fishery.

This analysis does not touch on the question of whether the loss of catch biomass caused by taking fish early in the season represents a genuine loss of yield (i.e., usable product), or whether the lost yield consists of gonad or liver growth. This will be examined in-the future. However, yield projections are based on a conversion of yield in numbers to yield in biomass using weight-at-age vectors. If these weights at age are higher than those actually occurring in the catch, a quota in biomass would impose a higher mortality rate on the stock than intended.

Estimating Weight at Age for Stock Assessment Models

Estimates of weight at age are required both by the stock synthesis model (Methot 1989) and by the population simulation model (Francis 1985) used to determine the long-term productivity of the resource. The estimates of weight at age in Dorn and Methot (1990) were updated with estimates of fishery and population weight at age for 1989. Mean length at age (Table 3) was

converted into weight at age using an exponential length-weight relationship (coefficients in Table 3; Ricker 1975). To reduce the effect of measurement error on the estimates of weight at age, the LOWESS scatterplot smoother in the S statistical package (Cleveland 1979) was used to smooth the weight-at-age data. Separate weight-at-age vectors were calculated for the U.S. fishery, the Canadian fishery, and the entire west coast population.

1989 ASSESSMENT SURVEYS OF PACIFIC WHITING

Bottom Trawl Survey

<u>Survey Design</u>

The fifth triennial National Marine Fisheries Service (NMFS) groundfish survey of west coast continental shelf groundfish resources was conducted between 7 July and 29 September 1989, by the Resource Assessment and Conservation Engineering Division (RACE) of the Alaska Fisheries Science Center (AFSC). Previous surveys in this series occurred in 1977, 1980, 1983, and 1986 (Dark et al. 1980, Weinberg et al. 1984, Coleman 1986, Coleman 1988). The primary objectives of the 1989 survey were to assess the abundance of Pacific whiting and juvenile (age l+) sablefish (<u>Anoplopoma fimbria</u>). The survey focused on these two species while maintaining the broader, multispecies assessment objectives of previous surveys. Accordingly, a background sampling intensity comparable to the low density sampling in prior surveys was used for the entire survey area, with heavier sampling concentrated in four areas identified as high density strata for juvenile sablefish: Juan de Fuca Canyon, Astoria Canyon, Half Moon Bay, and Morro Bay.

The survey was conducted aboard two chartered commercial trawlers and extended northward from Point Conception, California, to central Vancouver Island (Nootka Sound), British Columbia, Canada (lat. 34°30'N to lat. 49°35'N). Stations were-sampled at predetermined locations between 55 and

366 m in depth (30 to 200 fathoms). Both vessels used standardized

Northeastern high-opening bottom trawls equipped with roller gear. The

fishing dimensions of the trawl were measured aboard each vessel using a

Scanmar net measurement system. Preliminary inspection of the data revealed

that the net used on the Pat San Marie had a 13.4 m mean path width, while

that used aboard the Golden Fleece had a 12.4 m mean path width.

The typical reduction in whiting and juvenile sablefish catch rates at

depths from 165 to 183 m served as the rationale for stratification at 183 m.

Thus , the shallow stratum ranged from 55 to 183 m, and the deep stratum from

184 to 366 m. Tracklines were drawn across both depth strata at 18.5 km

intervals. In the four high-density, juvenile sablefish strata, additional

tracklines were drawn midway between the 18.5 km tracklines, crossing only the

55 to 183 m depth stratum. Stations were randomly located along tracklines at

the rate of one station per 7.4 km in the shallow stratum, and one station per

9.3 km in the deep stratum. At least one trawl station was assigned to each

depth stratum along each trackline. The two vessels fished alternate

tracklines (alternate pairs in the high-density areas to minimize and to

assess the effects of between-vessel differences in fishing power.

A total of 601 predetermined stations were established for this survey;

46 stations were abandoned where they were considered untrawlable. Successful

trawl hauls were achieved at 540 of the 555 survey stations attempted. Tows

were made at a speed of 3 knots and were 30 minutes in duration, allowing 3 to

10 minutes between setting the winch brakes and beginning the tow to

allow the net to settle to the bottom. Efforts were made to maintain a

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[1] Reference to trade names does not imply endorsement by the National Marine
Fisheries Service, NOAA.

constant towing depth. Catches were sorted, weighed, and counted by species, and a variety of biological data (age, length, weight, and maturity of individual specimens) were taken.

Results: Distribution and Abundance of Pacific Whiting

Pacific whiting dominated the catches in all INPFC areas except Conception and Vancouver. In the Conception area it was fourth in abundance after bocaccio (Sebastes paucispinis), Pacific sanddab (Citharichthys sordidus), and widow rockfish (S. entomelas). It was second in abundance to spiny dogfish (Squalus acanthias) in the Vancouver area. The shallow depth stratum was typically dominated by Pacific whiting, although shallow catches in the Conception and Vancouver areas were dominated by bocaccio and spiny dogfish, respectively. Pacific whiting was also the dominant species in the deep stratum everywhere except the Eureka INPFC area, where it was second to sablefish. The distribution of Pacific whiting catch per unit effort (CPUE) observations is shown in Figure 8 by individual haul, grouped by three levels of magnitude. Age-structured estimates of abundance and biomass by INPFC region for Pacific whiting are given in Tables 6 and 7. These estimates were produced using standard area-swept methods (Weinberg 1984) to estimate total biomass by region. The biomass by region was further partitioned using the data from the biological samples (age, length, and weight) to produce the age-structured estimates of abundance and biomass. Methods are described in Weinberg (1984).

Acoustic Survey

Survey Design

The triennial acoustic-midwater trawl survey of the coastal Pacific whiting population was conducted using the National Oceanic and Atmospheric Administration (NOAA) research vessel Miller Freeman during the periods

22 July-4 August and 7-25 August 1989. The survey was comparable in extent to those conducted in 1977, 1980, 1983, and 1986. The major objective of the acoustic survey was to provide data for the estimation of age- and size-specific biomass and population abundance of Pacific whiting.

Survey data were collected along a series of parallel tracklines spaced 10 nautical miles (nmi, 1 nmi = 1.852 km) apart and run east to west between the 55 m (30 fathoms) and 366 m (200 fathoms) depth contours starting from lat. 34°30'N and extending north to near lat. 50°00'N. (Point Conception to northern Vancouver Island). A chart shoving the survey area and transect locations is shown in Figure 9. All midwater trawling and acoustic surveys were conducted during daylight hours to avoid interception of nontarget species which ascend from the bottom into the water column at night. Transecting speed was usually l0-11 knots. Echo sign could consistently be detected and echo integration data collected to within 3 m of the bottom.

Acoustic data were collected with a 38 Khz. echo sounder and a digital echo integrator. The echo sounder's transducer was housed in a dead-weight vehicle that was towed behind the ship by an electro-mechanical cable at a depth of about 20 m. The acoustic data collection system was housed in a portable van mounted on the weather deck of the ship. Calibration of the system was accomplished in the following two ways: an indirect method using an acoustics measurement barge before and after the cruise and a direct (in situ) method using a standard sphere suspended under the transducer. Acoustic barge measurements were used to, determine the directivity pattern of the transducer while the in situ ball method supplied the remaining parameters necessary to scale echo integration values to fish density (kg/m^3). The in situ calibration was conducted during the first and last 2 days of the cruise.

Biological data and samples were collected and echo sign was identified throughout the cruise using a Northern Gold rope trawl equipped with 5 m^2 doors and 455 kg (1,000 lb.) tom weights. The codend was equipped with a 3.2 cm (1.25 inch) liner. An acoustic-linked headrope sounder was used to monitor the mouth opening (usually 15-18 m), and the position of the trawl in the water column (8-10 fathoms). Trawl hauls were made on selected echo sign to provide information on the biological composition of Pacific whiting and other species. Standard on-deck catch sorting and enumeration procedures were used. Catches were sorted completely, except when they exceeded about 1,000 kg; in such cases the catch was split and then sorted. Species compositions were determined in terms of weight and numbers. A subsample of manageable size (300-400 fish) from the sorted catch was then randomly selected for detailed examination and biological sample collection (size measurements, age structures, sexual maturity, sex ratio, individual weights, etc.). Trawl catch data were used only to identify and categorize the species and size compositions of fish represented by the various layers and groups of echo sign encountered during the survey. Estimates of age- and size-specific biomass and abundance of Pacific whiting were-produced using standard methods for analyzing acoustic surveys of fish populations as described by Dark et al. 1980.

<u>Survey Results</u>

A total of approximately 2,500 nmi of transect lines were run during which hydroacoustic data were continuously collected and 25 midwater trawl hauls were conducted. Most of the trawl catches consisted mainly of Pacific whiting. The percentage by weight represented by all species other than Pacific whiting in all trawl hauls combined amounted to only 2.2%. This small amount of contamination of the hydroacoustic data by nontarget species was

assumed to be insignificant, and no correction of the total estimated biomass of whiting was made.

Significant whiting aggregations were found from about lat. 37°30'N to lat. 50°00'N. The bulk of the whiting stock occurred in the Eureka, south Columbia, and Monterey INPFC areas. A chart showing the locations of the aggregations is given in Figure 10. Figure 10 is provided only as a reference to indicate the presence or absence of whiting occurrence; it does not imply how dense or abundant the fish were within any area or aggregation. Significant numbers of young-of-the-year whiting were found in the Conception INPFC area where they were in small, isolated aggregations (Fig. 10) that were associated with large quantities of nonfish echo sign. The abundance estimates given in this report for age-0 whiting (<20 cm) should be used only as indicators, since the degree of contamination of their echo sign by other species could not be determined with confidence. Fish smaller than 39 cm were found in the Monterey and Eureka areas and a trace of small fish continued into the south Columbia area. Most of the whiting population found throughout the survey area consisted of fish greater than 39 cm in length (Fig. 11). A consistent trend of increasing mean length with increasing latitude from the Eureka to Vancouver INPFC areas is noticeable. The effect is somewhat masked by the occurrence of some large fish in the southern and northern parts and very few large fish in the intermediate part of the survey area. The only age-0 fish encountered during the survey were in the Conception INPFC area. Significant numbers of whiting aged 2-4 years occurred only in the Monterey and Eureka INPFC areas and were not in exceptional abundance. Two cohorts, the 1984 and 1980 year class (age 5 and 9, respectively), were of greatest abundance in all areas except Conception. They contribute about 43% in numbers and 82% by weight, to the total pelagic portion of the whiting

population (Tables 8 and 9). These data do not indicate more than moderate

recruitment by any of the year classes younger than 1984.

Comparison of Combined Survey Results with Previous Surveys

Although we follow the usual practice of assuming that the two surveys

can be added to estimate the total abundance, it needs to be stressed that

this assumption has not been critically assessed. Recent investigations of an

inshore population of Pacific whiting have demonstrated that the fish dive

towards the bottom with the passage of trawl gear so that some of the fish

captured by trawl gear may actually be quite high in the water column

(Nunnallee 1991). However, the distinctly different age composition for the

acoustic and bottom trawl surveys in the same geographic area (See for example

the age composition in the Canadian zone in 1989, Tables 6 and 8) suggests

that at least some of the fish captured by the bottom trawl survey are not

vulnerable to acoustic sampling methods. Biomass by region (with 95%

confidence intervals) for the 1989 bottom trawl and acoustic surveys is given

in Table 10. A comparison of the 1989 estimates with earlier quantitative

surveys of Pacific whiting is given in Table 11 and Figure 12 (Dark et al.

1980, Weinberg et al. 1984, Nelson and Dark 1985, Coleman 1986, Coleman 1988,

Neal Williamson, Alaska Fisheries Science Center, National Marine, Fisheries

Service, NOAA, BIN C15700, 7600 Sand Point Way NE., Seattle, WA 98115. Pers.

commun., May 1989). The fraction of the total biomass estimate contributed by

the bottom trawl survey was 6% in 1977; it remained relatively constant at 10-

12% for the surveys in 1980, 1983, and 1986. In 1989, however, the bottom

trawl contributed 23% of the total survey biomass.

Numerical estimates of abundance for the Canadian portion of the

Vancouver INPFC area for 1977 and 1986 (Table 11), when the NMFS trawl surveys

ended at the international boundary, were obtained by the following procedure.

The sum of the trawl biomasses estimated for the Canadian portion of the Vancouver INPFC area by the surveys in 1980, 1983, and 1989 was divided by the sum of the acoustic biomasses for the same years to obtain a ratio. This ratio was multiplied by the acoustic biomass in 1977 and 1989 to estimate the trawl biomass for those years. Next it was assumed that the trawl age composition in 1977 and 1986 in the U.S. portion of the Vancouver area was representative of the age composition of the trawl biomass in the Canadian Vancouver area. Thus the ratio of the estimated trawl biomass in the Canadian Vancouver area to the trawl biomass in the U.S. portion of the Vancouver area was multiplied by numbersat age in the U.S. portion of the Vancouver area to estimate numbers at age in Canadian Vancouver area.

NATURAL MORTALITY ESTIMATION

New estimates of the natural morality rate were obtained by examining the decline in abundance of a year class from one triennial survey to the next. To reduce the possibility of misageing and sampling variability causing implausible estimates of the natural mortality rate, only the dominant year classes (1967, 1970, 1973, 1977, 1980, and 1984) were used in the calculations. A previous effort to estimate the natural mortality rate of Pacific whiting using the decline of groups of year classes between surveys (Hollowed et al. 1988) used the Baranov catch equations to estimate the natural mortality rate of Pacific whiting. Therefore, they make the assumption that the catch occurs continuously from one survey to the next. This assumption is reasonable if there are no trends in the exploitation rate from one survey to the next. However, since the fishery for Pacific whiting has increased substantially since 1986, we considered it important to develop a model that removes the catch from the population when it occurs. To do

this, a generalization of the catch equation used in cohort analysis (Pope 1972) was developed. If N is the estimated population abundance at the start of the 3-year time period, and N^1 is the number at the end of the time period, then

$$N' = N\,e^{-3M} - \sum_i c_i\,e^{-(3-d_i)M}\,,$$

where d_1 is the length of time from the start of the time period to when catch c_1 was removed from the population. This equation can be solved for M, the natural mortality rate, using the Newton-Raphson algorithm.

Table 12 contains the natural mortality estimates for the dominant year classes using the triennial stock assessment surveys in 1977, 1980, 1983, 1986, and 1989. Estimates in Table 12 for the natural mortality rate were slightly smaller than those calculated for the same year classes using the method in Hollowed et al. (1988)(mean difference 0.005, maximum difference 0.025). This indicates that the errors caused by trends in the harvest rate in the model used by Hollowed et al.(1988) are relatively minor. The estimates of natural mortality before 1983 tended to be higher for all ages than the estimates since 1983. It is possible to interpret these results as a shift in the natural mortality rate. However, we are reluctant to put this forward as a hypothesis because a single aberrant survey estimate of overall abundance would perturb in opposite directions the natural mortality estimates that use the abundance estimate as a starting value and those that use it as an ending value.

POPULATION ASSESSMENT

The abundance and mortality of Pacific whiting was assessed with the stock. synthesis model (Methot 1986, 1989, Dorn and Methot 1990). The

synthesis model is a separable catch-age analysis which uses survey estimates of biomass and age composition as auxiliary information. The synthesis model operates by simulating the dynamics of the population. Comparisons are made between the expected value of the observable characteristics of the population and the actual observations of the population from surveys and fishery sampling programs. The goodness of fit to these observations is evaluated in terms of log(likelihood). The total log(likelihood) is a weighted sum of the likelihood components for each type of data.

The model assumes that fishing mortality can be separated into an age-specific component and a year-specific component. A double logistic selectivity curve was used to model the age-specific survey and fishery selectivity (Dorn and Methot 1990). The year-specific fishing mortality rates are not estimated as parameters. Instead, they are tuned to the levels necessary to match the observed catch biomass. The model parameters are estimated by an iterative process which involves numerical estimation of the first derivatives of total log(likelihood) with respect to each parameter, and the Hessian matrix of mixed partial derivatives. The inverse of the Hessian matrix postmultiplied by the vector of first derivatives indicates how the parameters should be changed.

The observations for Pacific whiting are catch biomass and age composition for the U.S. and Canadian fisheries, and estimates of population biomass and age composition in the U.S. and Canadian zones from NMFS triennial groundfish assessment surveys. In last year's stock assessment (Dorn and Methot 1990), the catch at age for the two fisheries was combined and modeled as a single fishery. Last year's stock assessment also explored other ways of modeling the population, including a preliminary version of a model that separated the stock between the U.S. and Canadian zones. This year our

approach was to keep separate the catch statistics and survey estimates of abundance in the U.S. and Canadian zones. In the discussion and in the following tables we have used the terms "U.S. survey" and "Canadian survey" to identify the data from the NMFS triennial groundfish assessment surveys in U.S. and Canadian waters. The selectivity for each fishery and survey was modeled relative to the portion of the stock in its zone. In addition to the parameters normally estimated by catch-age analyses (initial age composition, recruitment in each subsequent year, and age-specific selectivity curves), we also estimate the parameters of a function that governs the annual migration of fish from the U.S. to Canadian waters.

The modeled population includes ages 2-15; age 15 is treated as an accumulator age. Most model runs covered the years 1977-89 --the time period for which there was age composition data for the U.S. and Canadian fisheries, and estimates of the total abundance of Pacific whiting from the triennial surveys. In last year's assessment, age composition data for 1973-76 from Polish researchers were included in the baseline estimation runs. These runs were used to estimate survey and fishery selectivity curves, annual migration curves, age composition at the beginning of 1977, and year-class strength for the 1975-87 year classes. Selectivity patterns and migration curves were fixed at the values estimated in these runs, and the time series was extended back to 1958 so that historical recruitments could be estimated. Body weights at age were set at year- and fishery-specific values for the years 1978-89. Fish from earlier years were assumed to have the same weight at age as those from 1978.

Geographic Catch-Age Analysis and Migration Curves

The U.S. and Canadian fisheries for Pacific whiting are confined to small regions--of the total geographic range occupied by the Pacific whiting

population.   Each fishery, obviously, is restricted to its respective national
zone.   A ban on all foreign processing south of lat. 39°00'N, and a ban on
processing by Soviet, Polish, and mainland Chinese vessels north of lat.
48°00'N further limits the U.S. joint venture fishery.   These fisheries
harvest a population that changes in composition from south to north along the
coast.   Immature age groups are most abundant off the California coast.   As a
year class becomes older, its summer feeding migrations extend further north,
and by age 5 the fish begin appearing in the Canadian zone in significant
numbers (Bailey 1981).   Using an assessment model with geographic structure
allows us to more accurately model U.S. and Canadian fisheries.   This
capability has become essential in recent years as exploitation rates have
increased at a different pace on either side of the border.

   Geographic structure is included in the model by dividing the population
into U.S. and Canadian components at the start of the year.   The usual
equations governing the population dynamics (exponential mortality and Baranov
catch equations) are assumed to apply in each zone.   At the end of the year,
all the fish from both zones are assumed to mix on the spawning grounds off
California.   The population is split between the U.S. and Canadian zones using
a migration curve, defined as the age-specific fraction (in numbers) of the
population migrating into the Canadian zone.   Based on an analysis of survey
data (Dorn and Methot 1990), we modeled this migration curve using a modified
logistic function

$$m(t) = \frac{p_3}{1 + e^{[-p_2(t-p_1)]}} \ ,$$

where t is age in years, p_1 is the inflection age, p_2 is the slope, and p_3 is
the fraction of the oldest age group migrating into the Canadian zone.   This
curve describes the mean migratory behavior of the population for all years.

However, since year-to-year variability in the fraction migrating into Canadian waters has been observed, an annual migration coefficient, p_y, is also estimated. This annual migration coefficient modifies the parameters of the mean migration curve as follows:

$$p_1(y) = p_1 + p_4 \, p_y \, ,$$

$$p_3(y) = p_3 + p_y \, ,$$

where p_4 is an additional parameter that makes the change in p_1 for a year proportional to the change in p_3. Coupling the change in the inflection age for a given year with the fraction of the older fish migrating into Canada is a way of modeling the observation that years when a higher than usual fraction of the older fish migrate into the Canadian zone are also years when more of the younger fish are found in the Canadian zone.

Modeling the annual variability in migration increases the total log(likelihood) from -821.98 to -631.22, a sizable improvement in fit (Table 13). Changing from a model with a single year-invariant migration curve to a model where annual migration coefficients are estimated only for the survey years produces most of the improvement in fit. The fit to the Canadian fishery age composition data improves the most, although the fit to all the data components improves. Changing to a model with annual migration coefficients for all years further increases the total log(likelihood). All the increase is due to an improved fit to the Canadian fishery age composition data (Table 13). Estimated migration curves for 1982-89 are shown in Figure 13. In 1983, a much higher than usual fraction of the older age groups migrated into the Canadian zone. In 1985 and 1989, a smaller than usual fraction of the older age groups migrated into the Canadian zone. Table 14

contains the population numbers at age in each geographic zone for the years
1977-89 as estimated by the stock synthesis model.

Modeling Survey Abundance and Selectivity

The zone-specific biomass estimates from the triennial surveys were
adjusted because of incomplete coverage of potential Pacific whiting habitat
in some years. The first of these adjustments involved the surveys in 1977
and 1986, when the trawl survey ended at the international boundary. Details
of this adjustment are described above. A second adjustment involved all the
surveys. We accept the conclusions of qualitative Canadian acoustic surveys
along the west coast of Vancouver Island and into Queen Charlotte Sound (Mark
Saunders, Pers. commun., June 1990) that the triennial NMFS surveys have not
extended to the northern limit of the summer distribution of the Pacific
whiting. Northern expansion factors were calculated for the survey biomass in
the Canadian zone pending improved surveys of Pacific whiting biomass from
these northern regions. The expansion factors, calculated for each survey
year, were based on the ratio of whiting habitat in the surveyed area to the
potential whiting habitat along the 100 fathom isobath north of the survey
limit. The estimated biomass north of the survey was 14% of the surveyed
biomass in Canada in 1977, 1980, and 1989; 20% in 1983; and 23% in 1986 (Mark
Saunders, Pers. commun., June 1990). The expansion factor was different for
different survey years because the northern limit of the NMFS surveys varied
from year to year. All of the stock synthesis models described in this report
used the expanded survey biomass estimates for the Canadian zone.

Separate selectivity curves were used for the triennial surveys in the
U.S. and Canadian zones. For the U.S. survey, separate selectivity
coefficients were estimated for the youngest age groups; otherwise, the
selectivity was assumed to be 1.0. For the Canadian survey, the youngest age

groups were assumed to have a selectivity of 1.0, but a descending logistic curve was used to describe the declining selectivity of the older ages.

Table 15 contains a range of different hypotheses concerning the selectivity of the younger age groups by the U.S. surveys. The options presented are 1) all age groups are fully selected; 2) only the selectivity coefficient at age 2 is estimated; 3) selectivity coefficients are estimated at both ages 2 and 3; and 4) selectivity coefficients are estimated at ages 2-4, and all other ages are fully selected. When the assumption that the younger ages are fully selected is relaxed, the fit of the model improves. Most of the improvement, as measured by the change in the overall log(likelihood), occurs when the model is allowed to estimate the selectivity of the age-2 fish. Estimated biomass for the start of 1990 also increases as the selectivity of the younger fish is allowed to be less than 1.0. This increase is due to upward revisions in the size of the 1984 year class, surveyed at age 2 in 1986, and the 1987 year class, surveyed at age 2 in 1989. Our subsequent analyses are based on the third option, where selectivity coefficients were estimated for the age-2 and age-3 fish. We made this choice because the triennial surveys have not covered the range of immature Pacific whiting, which extends well south of Point Conception (Bailey and Francis 1985). The selectivity coefficients should be well estimated at ages 2 and 3 because large year classes have been surveyed at those ages: the 1984 year class at age 2 in 1986, the 1977 year class at age 3 in 1980, and the 1980 year class at age 3 in 1983. We recognize, however, that the question of the availability of the young fish to the surveys will need to be revisited in the future as the 1984 and 1987 year classes move through the population.

Fishery Selectivity

Selectivity patterns for the U.S. and Canadian fisheries were modeled using double logistic selectivity curves. These selectivity curves apply to the fraction of the population found in each nation's zone. Figure 14 shows the estimated selectivity curves for the U.S. and Canadian fisheries. Both fishery selectivity curves are dome-shaped, with the U.S. fishery curve reaching a maximum at age 8, and the Canadian fishery curve reaching a maximum at age 11. The ascending limb of the Canadian selectivity curve is poorly determined because few of the younger fish are found in the Canadian zone. Since we have removed the effect of different mean age structure in each zone on fishery selectivity by using a geographic model, one would expect that the selectivity curves for the two fisheries would be approximately the same. Selectivity should be based exclusively on the physical characteristics of the gear (i.e., mesh size) and the age-specific behavioral characteristics of the population. We suspect that the U.S. fishery selectivity curve focuses the activity of the fishery on younger fish more than the Canadian fishery because the U.S. fishery can target on strong year classes at a young age by shifting south in the U.S. fishing zone. This opportunity is not available to the Canadian fishery.

Emphasis on Survey Biomass Likelihood

The emphasis placed on each component of the total log(likelihood) function determines how closely the model's estimates will approach the observations of that type. By varying the emphasis factors one is able to detect inconsistencies among the types of data. We investigated the sensitivity of the results to the emphasis on the likelihood component for surrey biomass (Table 16). Equal weights were given to the survey biomass estimates in the U.S. and Canadian zones. Survey biomass is an extremely

important element in the estimation procedure because it links the information in catch-age data on relative year-class strength with an absolute measure of abundance. The model tends to match the 1980 and 1989 survey biomass values very closely (Fig. 15). In 1977 and 1983, the model's expected survey biomass was greater than that actually observed. In 1986, the expected survey biomass was less than that observed by the surveys. As shown in Table 16, an increase in the emphasis on the likelihood component for survey biomass causes changes in the estimated strengths of the large year classes. These changes improve the fit to survey biomass, but degrade the fit to the U.S. fishery age composition, the Canadian fishery age composition, and to the survey age composition in each zone (Fig. 16). We selected an emphasis level of 5.0 to provide a reasonable compromise between the fits of the various types of data.

We also investigated the influence of the 1989 survey biomass observation on our current assessment of the stock. An ideal situation would be one in which the predicted survey biomass in 1989 matches the observed biomass even when no weight is placed on it in the estimation procedure. Figure 17 contrasts the estimates of recruitment and population biomass for two estimation runs of the model. In the first run the 1989 survey biomass is given the same weight as the other survey biomass observations. In the second run the 1989 survey biomass is given no weight in fitting the model. The predicted survey biomass in 1989 is 95% of the observed survey biomass in the first run, but only 79% of the observed survey biomass in the second run. The model fits the 1989 survey biomass observation by increasing the abundance of the 1980 and 1984 year classes. An anomalous biomass observation at the end of the time series is probably easier to fit than an anomalous observation in the middle of the time series because the model has to balance the fit between that observation and the-observations occurring earlier and later.

Consequently, the success the model has in fitting the 1989 survey biomass when it is given normal emphasis should not lead us to conclude that it is a reliable estimate. Although we do not de-emphasize the 1989 survey biomass in our final model, we recognize its critical influence on our assessment of the current abundance -of the resource, and ultimately on our short-term projections of yield.

Natural Mortality Sensitivity Analysis

Natural mortality rates are not well known for most exploited marine fish populations, and the coastal Pacific whiting population is no exception. When there is a lack of sufficiently compelling evidence to the contrary, a constant mortality rate, irrespective of age, is generally adopted as a null model. Last year's Pacific whiting assessment (Dorn and Methot 1990) demonstrated that the observed rapid decline in abundance of the oldest age groups in the survey data was equally consistent with the assumption that these older fish are not sampled by present survey designs, or with the assumption that natural mortality increases with age. At moderate exploitation rates, these older fish would not be caught by either the U.S. or Canadian fishery, and thus the consequences of either assumption is most important when assessing the reproductive potential of the stock, as when calculating spawning biomass.

To assess the sensitivity of the model fit to the choice of a constant natural mortality rate, the natural mortality was varied between 0.16 and 0.36. The log(likelihood) was maximum between 0.24 and 0.26 (Fig. 18), indicating that the value of M - 0.237 estimated by the cohort decay method is a reasonable choice. This value was used in all other model runs. The model estimates a constant natural mortality rate of 0.252 when given an initial value of 0.237 and is allowed to produce its own estimate. However, since the

improvement in the fit is small--an increase of 4.0 units in the log(likelihood)) --we do not advocate using the natural mortality rate estimated by the model. This analysis does suggest that a natural mortality rate of 0.2, used in previous assessments, may have been slightly too low. The estimated biomass for the start of 1990 was sensitive to the choice of a natural mortality rate (Fig. 18). The estimated 1990 biomass was largest when a low natural mortality rate was used, and declined as the natural mortality rate was increased. From M = 0.18 to M = 0.28 there was little change in the estimated biomass for 1990.

Ageing Error

The problem of how to handle outliers in catch-age models has received little attention in the literature. In some cases it is fairly obvious that ageing error is the culprit, such as when the diagonal path of a strong year class through the catch-at-age matrix jumps a line. Since this usually occurs towards the margins of the catch-at-age matrix (the youngest and oldest age groups), the strategy we adopt is to accumulate the questionable age groups out towards the margins of the catch-at-age matrix. The expected catch of the accumulated age groups can then be compared with the observed catch of those age groups. We were able to use this technique in three instances. First, the strong 1970 year class began to blur into the 1971 year class in 1978. This apparent error was accommodated by accumulating at age 7 in 1978, 8 in 1979, 9 in 1980, etc. Second, previous analyses have noted that the strong 1977 year class appeared as 3-year-old fish in 1979 because of a small sample size in the age-length key for that year. This problem was accommodated by accumulating the age-2 and age-3 fish in both the data and the model's estimate for the year 1979. Finally, the strong 1961 year class was prominent in the 1965-68 samples (Dark 1975); in 1969, the age composition was dominated

by 7-year-old fish. We suspect that this age mode was actually the 1961 year class, misaged by one year. Therefore, we accumulated at age 7 in the 1969 age composition sample.

Systematic ageing error was incorporated into the model by assuming that the standard deviation of observed age increases linearly with true age. The parameters which define this linear trend are the fraction misaged at age 2 and the fraction misaged at age 15. Allowing the model to estimate these parameters can shrink the recruit estimates of the weak year classes to zero. If aging error is too large the abundance of the weak year classes can be accounted for entirely by spillover from the adjacent strong year classes. Because the otoliths of Pacific whiting are relatively easy to age, they are used by the AFSC Age and Growth Task to train new ageing technicians. Accordingly, we used percent agreement from reader-tester validations from the 1989 fishery age sample to provide a reasonable estimate of systematic ageing error (Mark Blaisdell, Alaska Fisheries Science Center, National Marine Fisheries Service, NOAA, 7600 Sand Point Way NE, BIN C15700, Seattle, WA 98115. Pers. commun., July 1990). A regression line constrained to pass through zero at age 2 was fit to the percent agreement for the most abundant age groups in the 1989 age sample (ages 2, 5, 9, 12). The fraction misaged was estimated to increase from 0% at age 2 to 25% at age 15.

Reconstruction of Historical Abundance and Recruitment

Prior to 1977, our sources of information on the coastal population of Pacific whiting begin to thin out. U.S. fishery age composition for the years 1973-76 is available from sampling conducted by Polish researchers (Morski Instytut Rybacki 1977). Dark (1975) provides estimates of age composition for the years 1965-69 obtained primarily from research cruises off the southern coast of Washington. Finally, a time series of yield in biomass for U.S. and

Canadian waters extends back to the inception of the large-scale fishery in 1966 (Bailey et al. 1982). These yields were reported by the foreign nationals conducting the fishery and were not subject to independent verification.

To model these data we begin by assuming that the population had an equilibrium age composition in 1957. Equilibrium age-2 recruitment was set at 1.2 billion fish--approximately the mean recruitment for the years 1958-89 as determined by preliminary runs. The abundance of this assumed equilibrium population will affect the estimated magnitude of the recruitment in the early years. However, as reported previously, this effect degrades rapidly (Dorn and Methot 1990). The age composition data from Dark (1975) came primarily from the southern coast of Washington, and so we expect them to represent a selectivity pattern different from that of the current coastwide U.S. surveys. We modeled these data as a nonquantitative survey, since no biomass estimates are available, and we used a separate double logistic function to model the selectivity pattern. To prevent the assumed equilibrium age composition from influencing the fit to the 1965-69 data, we truncated the 1965 samples at age 9, the 1966 samples at age 10, and so on. The 1969 age composition was accumulated at age 7, as noted above, because of an apparent bias in the ageing of the 8-year-old 1961 year class.

Population abundance and recruitment prior to 1977 were estimated by fixing most of the parameters of the model at values estimated using only the data for 1977 and later. Fishery and survey selectivity curves were fixed, as were estimates of recruitment abundance for 1977 and later. A single fixed mean migration curve was used rather than to attempt to model the interannual variability in migration for the earlier years. Although we estimated recruitment beginning with the 1956 year class, we do not support the

estimates for the 1956 and 1957 year classes because of their dependence on the assumed initial population level and the short duration they were observed as age 8-9 fish in 1965-66.

Preliminary runs of the model revealed that the Polish age composition data in 1975 was not consistent with the fishery selectivity pattern of other years. Most of the lack of fit was due to a much higher catch of age-2 fish than expected. In 1975, the fishery operated south of its normal range, with approximately 70% of the U.S. catch coming from the Monterey INPFC area. In our final model, we estimated a separate double logistic selectivity curve for the U.S. fishery in 1975. The selectivity of the age-2 fish was estimated as 0.19, as compared to a selectivity of 0.04 for the other years. The selectivity at age for this curve is given in Table 17. Other selectivity curves used in the model to reconstruct the historical time series of recruitment are also given in Table 17.

The reconstructed time series of recruitment (Table 18) is similar to that estimated in last year's stock assessment using the stock synthesis model (Dorn and Methot 1990). The 1961, 1970, 1973, 1977, 1980, and 1984 year classes again stand out as exceptionally strong year classes. Year classes from the late 1960s appear to have been less variable than those of the late 1970s and 1980s. Another possible explanation is that less precise ageing during the early 1970s caused the early year classes to appear more similar in size. Because we model the age composition data and the catch statistics from the 1960s differently, we now estimate the abundance of the 1961 year class at 3.502 billion fish at age 2 rather than 5.160 billion fish as was estimated in last year's assessment (Dorn and Methot 1990). Recruitment estimates for the 1980 and 1984 year classes are larger than last year's estimates. This change is due to the unexpectedly large 1989 survey biomass estimate and to the

different assumptions we make concerning the survey selectivity of the younger fish.

The estimates of population biomass are less variable than last year's estimates. Our revised recruitment estimate for the 1961 year class no longer produces a sizable increase in population biomass in the late 1960s. The larger estimates of recruitment for the 1980 and 1984 year classes prevent the large fishery removals of recent years from significantly reducing the population biomass.

The annual full recruitment fishing mortality rates in the U.S. and Canadian zones are shown in Figure 19. The Canadian fishing mortality rate was high in the late 1960s and early 1970s, dropped to very low levels in the mid- to late 1970s, then increased rapidly in the 1980s. The U.S. fishing mortality rate varied between 0.10 and 0.20 for most years. Recently, the U.S. fishing mortality rate has also increased.

Pacific Whiting Discard: Does it Matter?

Any analysis of discard in the Pacific whiting fishery must first acknowledge the complete lack of quantitative data on the magnitude of discard. Observer reports of floating rafts of dead whiting on the fishing grounds are most likely the result of catcher boats spilling codends that exceed delivery requests. The frequency of these events is unknown. Another situation where there may be significant discard of Pacific whiting is in domestic fisheries that target on other species. The triennial trawl surveys have consistently found that Pacific whiting dominates the biomass at all depth strata (Weinberg et-al. 1984; Nelson and Dark 1985; Coleman 1986; Coleman 1988). Since the domestic market opportunities for the sale of Pacific whiting are extremely limited, virtually all of the whiting bycatch in fisheries targeting on other species, especially rockfish, would be discarded

at sea.   It is reasonable to assume that these fisheries have the ability and
some motivation to avoid areas with the highest Pacific whiting catch rates.
Our approach to this issue was to investigate a range of plausible discard
levels from the directed fishery for Pacific whiting.   The results are
presented in Table 19.   As the level of discard was increased, the fit of the
model degraded slightly.   Estimated age 2+ biomass at the start of 1990
remained nearly identical regardless of the level of discard.   Apparently the
model responds to increasing discard rates by increasing the recruitment until
it can match the survey estimates of population biomass.   This analysis
suggests that if the discard rate remains constant from year to year, the
presence of moderate levels of discard does not seriously affect our ability
to assess the population.

ESTIMATION OF SUSTAINABLE YIELD

Population Dynamics

   The age-structured simulation model of Francis (1985), used in previous
stock assessments to estimate sustainable yield, was revised to correspond to
the geographic catch-age model used in population assessment.   Geographic
structure was included in the model by using a single mean migration curve to
split the stock between the U.S. and Canadian zones at the start of the year.
For the U.S. and Canadian components of the population, the equations for the
dynamics of the population are identical to that of earlier versions of the
model.   Based on an analysis of survey and catch data described earlier, the
natural mortality rate was assumed to be constant with respect to age at
0.237.   Separate weight-at-age vectors for the U.S. fishery, the Canadian
fishery, and for the population were used.   These were estimated by averaging
weight at age for the years 1978-89 separately for each source.   Since there

has been a substantial decline in weight at age for the past decade, this gave compromise estimates of weight at age that are larger than currently observed in the fishery, but smaller than 10 years ago. Calculating the total yield in biomass was considerably more straightforward than in previous models. The estimated catch at age in each zone was multiplied by the fishery-specific weight at age and summed over age to give the total yield.

Age-specific fishing mortality rates were modeled as the product of an annual fishing mortality rate and an age-specific selectivity coefficient. Separate vectors of selectivity coefficients, estimated by the stock synthesis model, were used for the U.S. and Canadian fisheries (Table 20). The annual control variable in this parameterization is the full recruitment fishing mortality in the U.S. zone, $F_{us}(y)$. Obtaining a fishing mortality rate for the Canadian zone requires a decision on how to allocate the resource between the U.S. and Canadian fisheries. We set the fishing mortality rate in the Canadian zone so that the percentage of the total yield harvested by the Canadian fishery would be equal to the percentage of the mature biomass expected to migrate into Canadian waters. This was calculated using the mean fraction of mature fish at age in each zone as estimated by the stock synthesis model. To estimate the split in mature biomass for a particular year, the projected numbers of mature fish at age for that year were split between the two regions using the mean migration curve, converted to biomass using zone-specific body weights at age, then summed over all ages to get the estimated total mature biomass in each zone. It should be emphasized that we are not recommending this procedure as an allocation plan. Our purpose is only to specify a reasonable allocation algorithm for the simulation runs.

Recruitment

Although establishing a stock-recruit relationship is an important element of assessing the productivity of the resource, a careful examination of the observed relationship between the female spawning biomass and recruitment (Fig. 20) does not disclose any obvious relationship over the range observed. In particular, the data shown in Figure 20 do not lend themselves to description by a parametric curve with a log-normal error assumption. Hollowed and Bailey (1989) use the time series methods of Welch (1987) to filter density independent variability from the recruitment time series of Pacific whiting. The resulting scatterplot of filtered recruitment versus egg production (proportional to female spawning biomass) shows a flat relationship over the range of historical levels of egg production. From this analysis they conclude that, at the observed levels of stock abundance, the occurrence of strong year classes cannot be directly attributed to stock abundance and may be linked to factors independent of population density such as environmental conditions.

The most durable hypothesis concerning environmentally controlled recruitment is a mainly empirical link between temperature and recruitment, The relationship is still significant (rank order correlation two-tailed P-value < 0.05) when using the recruitments from the stock synthesis model for the year classes 1959-86. Years with cold water temperatures (average January-March temperature in the second quadrant of Marsden square 120 < 15.0°C) have low mean recruitment, while years with warm water temperature (>15.0°C) have higher though more variable recruitment.

To simulate a recruitment time series we again used the bootstrap method adopted last year (Dorn and Methot 1990). The recruitment estimates for the year classes 1958-87 (30 years) from stock synthesis model form our sample

space.   By sampling with replacement from the observed recruitment time series, our simulated recruitment process has the following properties: 1) simulated recruitment is independent of female spawning biomass over the range of historical levels; 2) the recruitment time series has the same statistical properties as the observed recruitment, particularly the same mean and variance; and 3) strong assumptions about the pattern of variability in recruitment that are not supported by the data are avoided.

<div align="center">Harvest Strategies and Risk</div>

Without knowledge of the effect of harvesting on ability of the Pacific whiting population to produce successful recruitments in a highly variable ocean environment, we incur a risk of population collapse by taking a harvest. We assess this risk by focusing on the female spawning biomass.   This is defined as

$$SB = \sum_{t} POPN_t \times MATURE_t \times PROPFEM_t \times WEIGHT_t ,$$

where $POPN_t$ is the population number of an age group, $MATURE_t$ is the fraction of sexually mature females of an age group, $PROPFEM_t$ is the female proportion of total biomass of an age group, and $WEIGHT_t$ is the population weight at age.   Figure 21 shows a frequency histogram for 20 replicate 1,000-year simulations of an unexploited Pacific whiting population using the recruitment resampling method described earlier.   When an annual harvest is taken from the population, the distribution of female spawning biomass will be shifted towards lower mean levels of female spawning biomass.   The risk is the possibility that harvesting might lower the female spawning biomass to such low levels that it could no longer produce recruitment to sustain population abundance even when conditions are favorable for larval survival.

To assess this risk we used the empirical distribution of female spawning biomass for an unexploited population-as a benchmark against which we gauged the magnitude of the disruption that occurs when an annual harvest is taken from the population. We designated the 0.1 percentile of female spawning biomass as a cautionary level of female spawning biomass. This occurs at 457,000 t of female spawning biomass, which is 32% of the mean unfished female spawning biomass (Fig. 21). We assess the risk of a particular harvest strategy by determining the probability of female spawning biomass dropping below this level. The harvest strategies we develop maximize yield from the fishery subject to the constraint that this probability is at a selected level. Low-risk harvest strategies are those where the probability of dropping below this cautionary level is low, and high-risk strategies are those where the probability is high.

We acknowledge that the 0.1 percentile of unexploited female spawning biomass is an arbitrary level, and we do not argue that the probability of recruitment failure increases rapidly below this level, although we do note that it must increase rapidly below some level. The fact that the Pacific whiting population persists in an unexploited state at some stable level of mean abundance suggests that the distribution of unexploited female spawning biomass is sufficient to maintain the population through all but the most extraordinary of circumstances. The 0.1 percentile is a level below which the female spawning biomass has not dropped during our 32 years of observation. Our confidence in the assumption that recruitment is unaffected by female spawning biomass erodes rapidly below this point--hence the term cautionary level.

We consider several classes of harvest strategies: 1) a constant F strategy; 2) a variable F algorithm developed by Shuter and Koonce (1985); and

3) a hybrid strategy that uses a constant F strategy when female spawning biomass is above the mean level, and a variable F strategy when it is below the mean. For the variable F algorithm, fishing mortality in a given year (y) is calculated by

$$F_y = F_{opt}(SB_y/SB_{opt}),$$

where F_{opt} is the optimum level of fishing mortality, SB_y is the current female spawning biomass level, and SB_{opt} is the mean female spawning biomass for the optimal constant F strategy.

The variable F harvest strategy has been used to manage the Pacific whiting resource since 1985. It was considered superior to constant F strategies because in simulations it gave a higher mean yield for a given level of risk. It also provides more protection to the stock in a period of declining abundance by cutting back on the fishing mortality rate at low female spawning biomass levels. A disadvantage of this strategy is that it makes yield from the fishery extremely variable, and this variability necessarily includes large declines in the yield from one year to the next when a strong year, class moves out of the fishery. The economic and political consequences of the variable F strategy have not been confronted in the past simply because before 1988 the yield from the fishery was far below the recommendations.

Table 20 gives the parameters used to simulate the dynamics of the Pacific whiting population. Estimates of sustainable yield for a constant F strategy, a variable F strategy, and the hybrid harvest strategy are given in Table 21. The table entries were estimated by averaging 20 replicate 1,000-year simulations. To remove the effect of initial conditions, all simulations were run for 50 years before beginning to tabulate the summary statistics.

For each harvest strategy we present three levels of risk (low, moderate, and high) to bracket viable alternatives and to provide a middle course. It is important to bear in mind that the labels of low, medium, and high risk are relative designations, and are not intended to imply judgments about which strategy is best.

The risk categories were defined as follows. Under a low-risk strategy the probability of falling below the cautionary female spawning biomass level is 0.10; for moderate risk it is 0.20; and for high risk it is 0.30. Although the definitions of these categories are arbitrary, they result in fishing mortality rates that span the biological reference points commonly used to guide fisheries management decisions (Sissenwine and Shepherd 1987). The low-risk options are near a strategy where fishing mortality equals natural mortality (F - M). Under moderate-risk harvesting strategies, the mean female spawning biomass is between 48 and 54% of mean unexploited female spawning biomass --approximately equal to the 50% that the Graham-Schaefer surplus production model would predict for maximum sustainable yield (Ricker 1975). The high-risk strategies reduce mean female spawning biomass to 44-47% of the unexploited level and correspond more closely to a $F_{0.1}$ strategy. For reference, we also show in Table 21 the results of simulations using an exploitation rate that lowers the female spawning biomass to 35% of its pristine level. High exploitation rates are necessary to fish at the $F_{35\%}$ level because Pacific whiting become mature at a younger age than they recruit to the fishery. However, it should also be noted that age at first maturity for the coastal population of Pacific whiting has not been extensively studied, so the estimates of maturity used in the model are not based on reliable data.

Estimates of sustainable yield presented in Table 21 ranged between 168,000 and 202,000 t for the low-risk harvesting policies, between 205,000 and 226,000 t for moderate-risk harvesting policies, and between 227,000 and 247,000 t for the high-risk harvesting policies. The constant F strategy produced the lowest variability in yield, but also had the lowest mean yield. The variable F strategy had higher mean yield, but variability in yield was also higher. The hybrid strategy was intermediate in performance, both in mean yield and in the variability of yield. This strategy appears to offer a reasonable compromise policy that protects the stock at low levels of female spawning biomass, maintains relatively high mean yield, yet avoids the extreme variability in yield of the variable F strategy. Yield curves for the constant F policy, the variable F policy,. and the hybrid policy are shown in Figure 22.

YIELD FORECASTS FOR 1991-93 AND 1991 ACCEPTABLE BIOLOGICAL CATCH

Since 1967, the Pacific whiting fishery has been supported by strong year classes occurring every 3 or 4 years. The 1980 and 1984 year classes have dominated the catch in recent years. The 1984 year class constituted 62.4% of the 1989 U.S. fishery catch of whiting by number, and most of the remaining catch was contributed by the 1980 year class (25.8%). The projection of steeply declining yields in last year's stock assessment was a consequence of the advancing age of these two large year classes and the lack of significant recruitment since the 1984 year class. We have moderated our projections based on information that has become available since last year. The most consequential of this new information is the estimate of the population biomass from the 1989 stock assessment surveys. Despite an aggregate harvest of over 850,000 t between the 1986 and 1989 surveys, the

total biomass estimate in 1989 was only 24% lower than the 1986 estimate,
indicating a decline of approximately 500,000 t in population biomass. This
moderate decline is even more surprising when it is noted that 88% of the
population biomass in 1989 was age 5 and older, and should also have been
surveyed in 1986. The synthesis model increases the abundance of the 1980 and
1984 year classes to fit the 1989 survey biomass observation. Moreover, our
final synthesis model relaxes the assumption made in last year's assessment
that the younger age groups are fully selected by the triennial surveys. As a
result, the projections of declining spawning biomass as the 1980 and 1984
year classes move out of the population are not nearly as immediate nor as
steep as in last year's assessment (Fig. 23).

Evidence of significant recruitment to the population since the 1984
year class remains sketchy. A moderately abundant 1987 year class was
detected by the 1989 acoustic survey and is evident as a mode at 40 cm in a
preliminary tabulation of the 1990 fishery length frequency--but not as
prominently as the 1984 year class in 1987 (Fig. 24). The age-2 abundance of
the 1987 year class was estimated by the stock synthesis model as 0.903
billion fish, close to average recruitment for the years 1960-89. There is
also some evidence that the 1988 year class may also be of moderate size. The
trawl survey in 1989 encountered age-1 fish (Table 6), and the U.S. fishery
length frequency in 1990 shows the age-1 fish as a flat shoulder at 34 cm on
the ascending limb of the histogram.

Most of the indeterminacy in the yield projections for 1991-93 is due to
our uncertainty of the year-class sizes for 1989-91. Our ignorance is most
crucial with respect to the timing of the next strong year class. We consider
four alternative recruitment scenarios. In scenario A, the 1989 year class is
strong, followed by weak year classes in 1990 and in 1991. In scenario B, the

1989 year class is weak, the 1990 year class is strong, and the 1991 year class is weak. In scenario C, a strong year class does not occur until 1991. Scenario D represents the worst case: weak year classes in all 3 years. A strong year class is operationally defined as the mean of the top 25% of the historical recruitments (age-2 abundance 3.526 billion), and a weak year class as the mean of the historical recruitments below the 50th percentile (age-2 abundance 0.283 billion).

Although these recruitment scenarios are intended to represent plausible alternatives, we do not argue that they are equally likely. The preliminary tabulation of the length frequency for the 1990 U.S. fishery shows no sign of a mode of small fish less than 30 cm that would indicate a strong 1989 year class (Fig. 24). The detection of age-0 fish by the acoustic survey in 1989 is worth mentioning even though the abundance estimate is too unreliable to be used in quantitative projections. Also, 1989 and 1990 were cold years (Jerrold Norton, Pacific Fisheries Environmental Group, P.O. Box 831, Monterey, California 93942. Pers. commun., April 1990), and a strong year class has never been observed during a cold year.

We used a deterministic version of the population simulation model with the information in Table 22 to forecast the yield for 1991-93. The population abundance for the beginning of 1989 (estimated by the stock synthesis model) was updated to the start of 1991 by removing the yield for 1989 and 1990. For the 1988 year class, age-2 recruitment was set to 1.230 billion (the mean 1960-89 recruitment), reflecting our conclusion that it is most likely of moderate size. The weight-at-age vectors given in Table 22 for the U.S. catch, the Canadian catch, and the Pacific whiting population are averages of the weight at age for 1987-89. These vectors represent the weight at age currently observed in the stock rather than the long-term average.

Table 23 gives the projected yields for 1991-93 under the hybrid policy and the constant F policy for the different risk levels discussed in the previous section. The yield for 1991 ranged from 146,000 to 327,000 t. The risk level contributes about 106,000 t of the range, the recruitment scenario contributes about 12,000 t, and the F strategy contributes about 63,000 t. The low-risk scenario provides greater stock protection than seems necessary, thus it is not recommended. The moderate-risk, hybrid strategy specifies a total yield of 253,000 t for recruitment scenarios B, C, and D, which assume that the 1989 year class is weak. The high-risk hybrid strategy specifies a total yield of 311,000 t for the same situations. In view of the uncertainties involved in our estimates of the current stock abundance, we feel reluctant to recommend the high-risk option. We propose a total ABC of 253,000 t in 1991. Pending a binational agreement on an allocation plan, we make no recommendation on allocating the yield between the U.S. and Canadian fisheries.

In 1992, the yield projections ranged from 133,000 to 295,000 t. Under the optimistic recruitment scenario A, which assumes a strong 1989 year class, the yield for 1992 will still be close to the 1991 yield. A strong 1989 year class will not have a great deal of influence on the female spawning biomass or the recruited biomass until 1992 and later. Under the less optimistic scenarios B, C, and D, the yield for 1992 will drop below the yield for 1991. Because of the high level of uncertainty concerning the 1989 and 1990 year classes, forecast of the yield for 1993 is purely speculative. However, it is unlikely to exceed 313,000 t, and may be as low as 116,000 t. Under most recruitment scenarios, yield is projected to show a declining trend over the next 3 years.

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Table 1 .--Annual catches of Pacific whiting (1,000 t) in U.S. and Canadian management zones by foreign, joint venture (JV), and domestic fleets, 1966-89.

Year	U. S.				Canada				Combined total
	Foreign	JV	Domestic	Total	Foreign	JV	Domestic	Total	
1966	137.000	0.000	0.000	137.000	0.700	0.000	0.000	0.700	137.700
1967	168.699	0.000	8.963	177.658	36.713	0.000	0.000	36.713	214.371
1968	60.660	0.000	0.159	60.819	61.361	0.000	0.000	61.361	122.180
1969	86.187	0.000	0.093	86.280	93.851	0.000	0.000	93.851	180.131
1970	159.509	0.000	0.066	159.575	75.009	0.000	0.000	75.009	234.584
1971	126.485	0.000	1.428	127.913	26.699	0.000	0.000	26.699	154.612
1972	74.093	0.000	0.040	74.133	43.413	0.000	0.000	43.413	117.546
1973	147.441	0.000	0.072	147.313	15.125	0.000	0.001	15.126	162.439
1974	194.108	0.000	0.001	194.109	17.146	0.000	0.004	17.150	211.259
1975	205.654	0.000	0.002	205.656	15.704	0.000	0.000	15.704	221.360
1976	231.331	0.000	0.218	231.549	5.972	0.000	0.000	5.972	237.521
1977	127.013	0.000	0.489	127.502	5.191	0.000	0.000	3.453	130.955
1978	96.827	0.856	0.689	98.372	3.453	1.814	0.000	6.464	104.836
1979	114.909	8.834	0.937	124.680	7.900	4.233	0.302	12.435	137.115
1980	44.023	27.537	0.792	72.352	5.273	12.214	0.097	17.584	89.936
1981	70.365	43.556	0.839	114.760	3.919	17.159	3.283	24.361	139.121
1982	7.089	67.464	1.024	75.577	12.479	19.676	0.002	32.155	107.732
1983	0.000	72.100	1.050	73.150	13.117	27.657	0.000	40.774	113.924
1984	14.722	78.889	2.721	96.382	13.203	28.906	0.000	42.109	138.491
1985	49.853	31.692	3.894	85.439	10.533	13.237	1.192	24.962	110.401
1986	69.861	81.640	3.463	154.964	23.743	30.136	1.774	55.653	210.617
1987	49.656	105.997	4.795	160.448	21.453	48.076	4.170	73.699	234.147
1988	18.041	135.781	6.876	160.698	39.714	50.182	0.594	90.491	251.189
1989	0.000	203.578	7.418	210.996	31.589	66.256	0.000	97.845	308.841
Mean 1966-89				131.555				38.070	169.625

Sources: 1966-80 from Bailey et al. 1982; 1981-89 from Pacific Fishery Information Network (PacFIN), Pacific Fishery Management Council, Metro Center, Suite 170, 2000 SW. First Avenue, Portland, OR 97201; Canadian catches reported by Mark Saunders, Pacific Biological Station, Department of Fisheries and Oceans, Nanaimo, B.C. V9R 5K6, Pers. commun., January 1990.

Table 2.- -Catch at age (millions of fish) for the Pacific whiting fisheries, 1978-89. Separate tables are given for the U.S. fisheries, the Canadian fisheries, and the combined fisheries. These totals are the aggregate catch from the foreign, joint venture, and domestic fisheries.

| | | | | | | | | Age | | | | | | | | |
Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Total
							U.S. fisheries									
1978	0.01	0.02	4.56	8.58	51.87	9.48	20.32	38.57	5.74	2.48	1.28	0.52	0.20	0.05	0.01	143.69
1979	0.00	4.34	8.74	17.41	10.15	48.01	15.47	29.48	20.82	4.25	1.70	0.50	0.22	0.05	0.03	161.16
1980	0.00	0.13	24.67	2.16	6.90	7.16	20.11	9.57	11.99	9.92	1.74	1.35	1.01	0.59	0.14	97.42
1981	13.38	1.25	2.30	97.62	6.89	9.64	6.77	23.33	6.26	7.24	7.05	0.95	0.48	0.12	0.13	183.43
1982	0.00	27.51	1.93	1.57	57.88	5.02	5.78	5.02	11.96	2.43	2.53	4.64	0.34	0.13	0.03	126.77
1983	0.00	0.00	86.60	7.22	3.63	36.79	4.68	3.72	3.32	5.24	1.62	1.00	1.00	0.16	0.14	155.12
1984	0.00	0.00	2.59	164.97	7.18	5.18	17.54	2.17	1.24	0.82	1.34	0.21	0.20	0.31	0.03	203.78
1985	2.27	0.55	1.32	12.36	113.50	9.74	4.30	6.75	0.61	0.34	0.24	0.36	0.00	0.00	0.00	152.34
1986	0.00	62.92	12.88	1.85	9.34	171.79	21.55	10.76	12.45	1.53	1.05	0.38	0.79	0.15	0.05	307.49
1987	0.00	0.00	124.20	6.58	1.68	2.72	151.56	7.89	3.09	14.87	0.57	0.15	0.15	1.25	0.00	314.71
1988	0.00	1.22	1.31	172.76	8.02	1.40	2.60	96.93	5.16	0.72	8.32	0.15	0.24	0.00	0.65	299.49
1989	0.00	8.65	9.57	3.88	257.20	7.80	2.46	2.74	106.63	6.62	0.87	5.37	0.03	0.12	0.57	412.51
							Canadian fisheries									
1978	0.00	0.00	0.00	0.20	0.35	0.28	1.06	1.31	1.12	0.62	0.48	0.21	0.18	0.09	0.00	5.90
1979	0.00	0.00	0.00	0.21	0.62	1.30	1.14	2.10	3.02	1.10	0.79	0.37	0.25	0.17	0.12	11.18
1980	0.00	0.00	0.00	0.00	0.47	0.62	2.46	0.92	1.18	6.74	1.27	0.62	0.62	0.20	0.00	15.07
1981	0.00	0.00	0.00	1.01	0.27	1.41	1.38	4.28	0.85	2.36	6.18	1.49	0.60	0.85	0.00	20.66
1982	0.00	0.00	0.00	0.69	13.35	1.10	1.44	1.41	4.41	1.00	0.78	6.04	0.59	0.47	0.00	31.27
1983	0.00	0.06	14.02	1.03	1.80	32.15	1.29	1.87	1.67	5.59	0.77	0.26	3.41	0.26	0.13	64.30
1984	0.00	0.00	1.11	13.27	1.73	9.26	20.86	2.04	2.35	1.54	4.81	0.93	0.80	2.65	0.37	61.71
1985	0.00	0.06	0.06	2.45	8.03	1.65	3.25	9.62	0.49	0.55	0.55	1.65	0.37	0.00	1.59	30.33
1986	0.00	0.14	0.14	0.28	3.97	38.41	2.41	2.41	11.48	1.28	0.57	0.99	1.42	0.43	1.42	65.33
1987	0.00	0.00	0.90	0.60	0.15	2.56	70.71	2.86	2.86	10.38	0.60	0.45	1.20	0.90	1.20	95.38
1988	0.00	0.00	0.31	15.28	0.62	1.13	2.36	66.66	2.26	1.44	7.90	0.51	0.21	0.21	0.62	99.48
1989	0.00	0.00	0.20	0.59	35.55	0.20	0.39	0.59	69.34	1.76	1.37	8.59	0.39	0.20	1.17	120.32
							Combined fisheries									
1978	0.01	0.02	4.56	8.78	52.21	9.76	21.38	39.88	6.86	3.10	1.76	0.73	0.38	0.14	0.01	149.58
1979	0.00	4.34	8.74	17.62	10.76	49.31	16.61	31.58	23.83	5.34	2.49	0.87	0.46	0.22	0.15	172.34
1980	0.00	0.13	24.67	2.16	7.36	7.77	22.57	10.49	13.16	16.65	3.00	1.97	1.62	0.78	0.14	112.49
1981	13.38	1.25	2.30	98.63	7.16	11.05	8.16	27.60	7.11	9.60	13.23	2.44	1.08	0.97	0.13	204.09
1982	0.00	27.51	1.93	2.25	71.24	6.11	7.22	6.43	16.37	3.43	3.31	10.67	0.94	0.60	0.03	158.04
1983	0.00	0.06	100.61	8.25	5.43	68.93	5.96	5.58	4.99	10.83	2.39	1.26	4.41	0.42	0.27	219.42
1984	0.00	0.00	3.71	178.24	8.91	14.43	38.39	4.20	3.58	2.36	6.15	1.14	1.00	2.97	0.40	265.49
1985	2.27	0.61	1.38	14.81	121.52	11.39	7.55	16.37	1.10	0.89	0.79	2.02	0.37	0.00	1.59	182.67
1986	0.00	63.06	13.02	2.13	13.31	210.20	23.96	13.17	23.93	2.80	1.62	1.37	2.20	0.58	1.46	372.82
1987	0.00	0.00	125.10	7.18	1.83	5.28	222.27	10.74	5.95	25.25	1.17	0.60	1.35	2.15	1.20	410.09
1988	0.00	1.22	1.62	188.05	8.64	2.53	4.96	163.59	7.42	2.15	16.22	0.67	0.44	0.21	1.26	398.96
1989	0.00	8.65	9.76	4.46	292.75	8.00	2.85	3.32	175.98	8.38	2.24	13.96	0.42	0.31	1.74	532.82

Table 3.--U.S. and Canadian mean fishery length at age (cm) and coefficients
of a length-weight relationship (cm to g) for Pacific whiting in
1989.

Age (years)	Males		Females	
	U.S.	Canada	U.S.	Canada
Length at age				
2	32.8	---	33.1	---
3	36.9	---	38.3	48.0
4	39.8	---	41.1	46.7
5	42.9	44.4	43.6	45.2
6	43.0	---	44.5	47.0
7	45.7	54.0	44.9	54.0
8	46.6	---	45.9	48.8
9	45.6	48.8	46.8	50.9
10	45.7	50.4	47.2	52.0
11	47.5	50.5	47.9	55.0
12	50.1	52.5	51.8	56.2
13	53.0	48.5	58.7	---
14	50.3	---	57.6	59.5
15+	53.5	70.0	53.5	59.6
Variable	Length-weight coefficients			
a	0.0361	0.0096	0.0080	0.0507
b	2.5232	2.8930	2.9168	2.4760

Sources: Jerald Berger, U.S. Foreign Fishery Observer Program, Alaska
Fisheries Science Center, National Marine Fisheries Service, NOAA, BIN C15700,
7600 Sand Point Way NE, Seattle, WA 98115, Pers. commun., May 1990. Canadian
statistics reported by Mark Saunders, Pacific Biological Station, Department
of Fisheries and Oceans, Nanaimo, B.C. V9R 5K6, Pers. commun., May 1990.

Table 4.--Analysis of variance table for the logarithm of Pacific whiting weight, using the logarithm of length as a covariate.

Source	df	SS	Mean square	F-value	P > F
Area	2	0.015	0.0075	0.586	0.5567
Time period	2	0.190	0.0950	7.422	0.0006
Age	13	1.311	0.1008	7.879	<0.0001
Sex	1	0.959	0.9585	7.488	0.0063
ln(length)	1	81.587	81.5870	6,373.984	<0.0001
ln(length) x area	2	0.022	0.0110	0.859	0.4237
ln(length) x time period	2	0.132	0.0660	5.156	0.0059
ln(length) x age	13	2.047	0.1575	12.302	<0.0001
ln(length) x sex	1	0.100	0.1000	7.813	0.0052
Error	3,027	38.753	0.0128		

Table 5.--Parameter estimates for a factorial analysis of variance of the logarithm of Pacific whiting weight using the logarithm of length as a covariate. The geographic areas used as factor levels are the same as the geographic strata used to compile catch at age and length at age: EUR (the intercept characteristic)--Monterey and Eureka INPFC areas, SCOL --south Columbia INPFC area, VNC --north Columbia and U.S. Vancouver INPFC area. The time periods used as factor levels are early (April-June), middle (July-August), and late (September-November).

Parameter	Estimate	SE of estimate
Intercept	-13.150	0.774
Area		
SCOL	-0.262	0.249
VNC	-0.275	0.286
Time period		
Middle	0.839	0.226
Late	0.766	0.263
Age		
2	-1.105	1.493
3	3.107	1.903
4	3.159	0.733
5	2.425	1.131
6	2.119	1.839
7	0.185	1.116
8	1.882	0.726
9	3.412	0.909
10	4.270	2.805
11	0.057	0.741
12	-4.297	3.208
13	0.145	3.440
15	-0.577	0.940
18	-0.361	0.228
Sex		
Female	0.482	0.176
ln(length)	3.343	0.231
ln(length) x Area		
SCOL	0.075	0.066
VNC	0.096	0.075
ln(length) x Time period		
Middle	-0.186	0.060
Late	-0.162	0.069

Table 5 .--Continued.

Parameter	Estimate	SE of estimate
ln(length) x Age		
2	0.284	0.429
3	-0.894	0.530
4	-0.900	0.220
5	-0.697	0.318
6	-0.622	0.495
7	-0.131	0.310
8	-0.565	0.218
9	-0.959	0.259
10	-1.175	0.728
11	-0.095	0.219
12	0.983	0.818
13	-0.114	0.876
15	0.072	0.260
ln(length) x sex		
Female	-0.130	0.047

Table 6 .--Estimated numbers at age (millions of fish) for Pacific whiting by INPFC area for 1989 west coast bottom trawl survey. These estimates were produced using standard area-swept methods (Weinberg 1984).

			INPFC Areas				
Age	Conc.	Mont.	Eureka	SCol.	NCol.-U.S. Van.	Can. Van.	Total
0	3.941	3.324	0.005	0.008	0.000	0.000	7.278
1	8.847	35.331	27.683	42.217	0.008	0.013	114.099
2	0.888	18.171	10.132	15.224	0.111	0.042	44.569
3	0.054	5.758	3.273	4.861	0.148	0.000	14.094
4	0.022	4.468	1.989	3.811	1.639	0.000	11.929
5	0.096	30.449	20.555	62.407	56.190	2.626	172.324
6	0.009	4.176	1.035	3.471	1.066	0.482	10.240
7	0.019	7.263	1.197	4.066	2.964	0.335	15.844
8	0.005	1.688	0.576	1.670	0.819	0.208	4.966
9	0.163	55.443	24.698	87.260	88.401	14.674	270.639
10	0.015	4.450	0.655	2.380	1.554	0.631	9.685
11	0.001	0.218	0.094	0.423	0.698	0.000	1.433
12	0.071	10.445	2.419	9.818	10.496	3.227	36.475
13	0.002	0.057	0.008	0.034	0.038	0.000	0.139
14	0.004	0.147	0.011	0.077	0.090	0.000	0.329
15	0.006	0.501	0.144	0.469	0.825	0.706	2.652
Total	14.143	181.890	94.473	238.196	165.048	22.945	716.695

Conc. = Conception.
Mont. = Monterey.
SCol. = Southern portion of Columbia.
NCol. - U.S. Van. = Northern portion of Columbia and U.S. Vancouver.
Can. Van. = Canadian portion of Vancouver area, up to lat. 49°35'N.

Table 7.--Estimated biomass at age (1,000 metric tons) by INPFC area for 1989 west coast Pacific whiting bottom trawl survey. These estimates were produced using standard area-swept methods (Weinberg 1984).

			INPFC Areas				
Age	Conc.	Mont.	Eureka	SCol.	NCol.- U.S. Van.	Can. Van.	Total
0	0.052	0.038	0.000	0.000	0.000	0.000	0.090
1	0.911	3.909	2.823	4.305	0.000	0.002	11.950
2	0.125	4.112	2.335	3.489	0.042	0.009	10.111
3	0.018	1.895	1.088	1.620	0.066	0.000	4.687
4	0.008	1.743	0.794	1.628	0.970	0.000	5.143
5	0.052	15.981	11.187	34.629	32.033	1.794	95.675
6	0.006	2.459	0.608	2.107	0.692	0.323	6.194
7	0.012	4.228	0.724	2.506	1.984	0.271	9.725
8	0.004	1.171	0.304	1.006	0.551	0.125	3.160
9	0.122	33.968	15.513	55.791	59.559	12.371	177.323
10	0.012	2.839	0.442	1.637	1.239	0.636	6.805
11	0.001	0.176	0.071	0.318	0.528	0.000	1.095
12	0.066	7.908	1.935	7.664	8.975	3.169	29.718
13	0.002	0.061	0.009	0.038	0.048	0.000	0.158
14	0.005	0.160	0.012	0.078	0.087	0.000	0.342
15+	0.008	0.673	0.225	0.684	1.147	0.998	3.735
Total	1.403	81.321	38.069	117.501	107.921	19.695	365.910

Conc. = Conception.
Mont. = Monterey.
SCol. = Southern portion of Columbia.
NCol.-U.S. Van. = Northern portion of Columbia and U.S. Vancouver.
Can. Van. = Canadian portion of Vancouver area, up to-lat. 49°35'N.

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Table 8 .--Estimated numbers at age by INPFC area (millions of fish) for 1989
west coast Pacific whiting acoustic survey. These estimates were
produced using standard methods for analyzing acoustic surveys of
fish populations. as described by Dark et al. 1980.

INPFC Areas

Age	Conc.	Mont.	Eureka	SCol.	NCol.-U.S. Van.	Can. Van.	Total
0	1955.386	0.000	0.000	0.000	0.000	0.000	1955.386
1	0.000	1.439	0.000	0.000	0.000	0.000	1.439
2	0.000	143.718	105.432	7.802	1.090	0.066	258.108
3	0.000	31.125	29.490	5.982	2.987	0.387	69.972
4	0.000	5.422	8.438	3.717	2.437	0.587	20.600
5	0.000	173.087	437.376	337.520	251.585	78.850	1278.419
6	0.000	3.826	8.291	6.587	4.880	1.675	25.259
7	0.000	2.102	3.737	3.375	3.076	1.446	13.736
8	0.000	1.811	3.664	5.446	4.697	2.051	17.668
9	0.000	63.116	108.900	144.230	136.580	65.866	518.692
10	0.000	2.487	5.509	6.582	5.886	2.626	23.089
11	0.000	0.301	0.365	0.819	0.835	0.440	2.761
12	0.000	6.144	4.841	6.913	8.840	6.559	33.297
13	0.000	0.000	0.000	0.000	0.000	0.000	0.000
14	0.000	0.000	0.000	0.000	0.000	0.000	0.000
15	0.000	1.525	0.000	0.205	0.859	0.592	3.182
Total	1955.386	436.105	716.043	529.176	423.751	128.554	4189.015

Conc. = Conception.
Mont. = Monterey.
SCol. = Southern portion of Columbia.
NCol.-U.S. Van. = Northern portion of Columbia and U.S. Vancouver.
Can. Van. = Canadian portion of Vancouver area, up to lat. 50°00'N.

Table 9.- -Estimated biomass at age (1,000 metric tons) by INPFC area for 1989 west coast Pacific whiting acoustic survey. These estimates were produced using standard methods for analyzing acoustic surveys of fish populations as described by Dark et al. 1980.

			INPFC Areas				
Age	Conc.	Mont.	Eureka	SCol.	NCol.-U.S. Van.	Can. Van.	Total
0	31.693	0.000	0.000	0.000	0.000	0.000	31.693
1	0.000	0.186	0.000	0.000	0.000	0.000	0.186
2	0.000	45.995	34.737	2.694	0.414	0.026	83.866
3	0.000	11.176	11.388	2.548	1.331	0.181	26.624
4	0.000	2.261	3.777	1.889	1.261	0.325	9.513
5	0.000	91.990	231.679	187.162	141.799	46.243	698.873
6	0.000	1.971	4.249	3.689	2.818	1.021	13.748
7	0.000	1.309	2.000	1.992	1.997	1.029	8.327
8	0.000	1.113	2.161	3.385	2.956	1.323	10.938
9	0.000	44.576	64.084	90.893	90.148	46.172	335.873
10	0.000	1.554	3.285	4.078	3.772	1.752	14.441
11	0.000	0.202	0.225	0.541	0.560	0.302	1.830
12	0.000	5.168	2.869	4.634	6.544	5.603	24.818
13	0.000	0.000	0.000	0.000	0.000	0.000	0.000
14	0.000	0.000	0.000	0.000	0.000	0.000	0.000
15+	0.000	1.936	0.000	0.185	0.778	0.626	3.525
Total	31.693	209.437	360.454	303.69	254.378	104.603	1264.255

Conc. = Conception.
Mont. = Monterey.
SCol. = Southern portion of Columbia.
NCol.-U.S. Van. = Northern portion of Columbia and U.S. Vancouver.
Can. Van. = Canadian portion of Vancouver area, up to lat. 50°00'N.

Table 10. -- Estimates of total biomass (1,000 metric tons) for the 1989 trawl and acoustic surveys by region. CV-coefficient of variation.

			INPFC Areas				
	Conc.	Mont.	Eureka	Columb.	U.S. Van.	Can. Van.	Total
TRAWL	1.362	83.472	37.694	205.729	21.501	22.765	372.520
CV	0.443	0.231	0.159	0.155	0.559	0.658	0.114
ACOUSTIC	31.693	209.437	360.454	420.665	137.405	104.603	1264.257
CV	0.090	0.118	0.242	0.089	0.397	0.243	0.091

Conc. = Conception.
Mont. = Monterey
Columb. = Columbia.
U.S. Van. = U.S. Vancouver.
Can. Van. = Canadian portion of Vancouver area, up to about lat. 50°00'N.

Table 11 .--Estimates of Pacific whiting biomass (1,000 metric tons) by region resulting from the NMFS bottom trawl and acoustic surveys in 1977, 1980, 1983, 1986, and 1989. The trawl survey estimates of biomass in the Canadian zone in 1977 and 1986 were interpolated by multiplying the acoustic biomass in 1977 and 1989 by the ratio of the aggregate trawl biomass for the Canadian Vancouver INPFC area for the surveys in 1980, 1983, and 1989 to the aggregate acoustic biomasses for the same years. The expansion factor used to account for the unsurveyed biomass north of survey grid has not been used to adjust these biomass estimates. BT -bottom trawl estimate, A-acoustic estimate, T-total.

| | | INPFC Areas | | | | | |
Year	Estimate	Mont.	Eureka	Columb.	U.S. Van.	Can. Van.	Total
1977	BT	17.707	10.153	31.548	6.523	10.376	76.307
	A	108.087	360.944	316.44	152.439	191.382	1129.292
	T	125.794	371.097	347.988	158.962	201.758	1205.599
1980	BT	140.948	11.338	19.858	11.770	4.385	188.299
	A	579.841	182.783	260.477	159.931	162.402	1345.434
	T	720.789	194.121	280.335	171.701	166.787	1533.733
1983	BT	19.164	43.559	56.665	8.068	1.352	128.808
	A	56.203	252.265	397.168	236.507	258.725	1200.868
	T	75.367	295.824	453.833	244.575	260.077	1329.676
1986	BT	95.953	45.228	78.568	19.403	15.414	254.566
	A	770.292	192.205	402.469	238.476	284.316	1887.758
	T	866.245	237.433	481.037	257.879	299.730	2142.324
1989	BT	84.834	37.694	205.729	21.501	22.765	372.523
	A	241.13	360.454	420.665	137.405	104.603	1264.257
	T	325.964	398.148	626.394	158.906	127.368	1636.780

Mont. = Conception and Monterey.
Columb. = Columbia.
U.S. Van. = U.S. Vancouver.
Can. Van. = Canadian portion of Vancouver area, up to about lat. 50°00'N.

Table 12. --Natural mortality estimates for Pacific whiting using estimates of abundance from the triennial NMFS surveys and the catches occurring from one survey to the next. Only the dominant year classes (1967, 1970, 1973, 1977, 1980, and 1980) were used to estimate natural mortality. Starting abundance, ending abundance, and aggregate catch are in millions of fish.

Year class	Mean age (years)	Years surveyed	Age range (years)	Starting abundance	Ending abundance	Aggregate catch	Natural mortality
1973	5.5	1977-80	4-7	462.020	270.756	134.484	0.053
1970	8.5	1977-80	7-10	666.795	91.087	103.154	0.544
1967	11.5	1977-80	10-13	42.525	12.932	4.689	0.338
1977	4.5	1980-83	3-6	1584.050	368.005	241.323	0.372
1973	8.5	1980-83	7-10	270.756	49.045	64.598	0.392
1970	11.5	1980-83	10-13	91.087	9.508	38.217	0.376
1980	4.5	1983-86	3-6	2747.967	1715.134	451.235	0.086
1977	7.5	1983-86	6-9	368.005	200.573	86.248	0.099
1973	11.5	1983-86	10-13	49.045	20.530	13.123	0.162
1984	3.5	1986-89	2-5	3151.929	1450.743	674.983	0.144
1980	7.5	1986-89	6-9	1715.134	789.331	603.107	0.087
1977	10.5	1986-89	9-12	200.573	69.772	59.060	0.191

Averages
Mean ages 4-6   0.164
Mean ages 7-9   0.281
Mean ages 10-12   0.267
Overall   0.237

Table 13. - -The effect of modeling the transboundary migration of Pacific whiting on the fit of the synthesis model as measured by the log(likelihood).   The headings "U.S. survey" and "Canadian survey" refer to the NMFS triennial survey data from the U.S. and Canadian zones respectively.   In the models reported here, both the U.S. and Canadian survey biomass estimates were given an emphasis weight of 5.0.   The alternatives considered were 1) a single migration curve, 2) annual migration coefficients estimated for the survey years only, and 3) annual migration coefficients estimated for all years.

Log(likelihood) components	Single migr. curve	Annual migr. coef. for survey years only		Annual migr. coef. for all years	
	Value	Value	Change	Value	Change
U.S. fish. age	-212.26	-205.31	6.95	-210.48	-5.17
Can. fish. age	-318.88	-271.61	47.27	-231.19	40.42
U.S. survey age	-193.75	-181.88	11.87	-185.98	-4.10
Can. survey age	-84.43	-63.38	21.05	-61.48	-1.90
U.S. surv. biom.	-0.74	6.31	7.05	5.45	-0.86
Can. surv. biom.	-1.79	5.46	7.25	6.13	0.67
Total	-821.98	-662.36	159.62	-631.22	31.14

Table 14. --Population numbers at age (millions of fish) for the coastal population of Pacific whiting as estimated by a geographic version of the stock synthesis model, 1977-89. Separate tables are given for the U.S. management zone, the Canadian management zone and the total west coast population.

Year	2	3	4	5	6	7	8	9	10	11	12	13	14	15
					Age (years)									
					U.S. management zone									
1977	295.0	234.0	747.0	163.0	126.0	580.0	92.0	66.0	43.0	34.0	26.0	5.0	48.0	180.0
1978	180.0	229.0	176.0	516.0	100.0	74.0	356.0	60.0	44.0	29.0	24.0	19.0	3.0	173.0
1979	2,162.0	140.0	172.0	121.0	320.0	60.0	46.0	237.0	41.0	30.0	20.0	17.0	14.0	135.0
1980	285.0	1,685.0	107.0	125.0	84.0	227.0	45.0	37.0	192.0	33.0	25.0	17.0	15.0	140.0
1981	355.0	223.0	1,287.0	77.0	82.0	51.0	138.0	28.0	24.0	126.0	22.0	17.0	12.0	114.0
1982	6,258.0	271.0	156.0	756.0	36.0	35.0	22.0	65.0	14.0	11.0	63.0	11.0	9.0	74.0
1983	333.0	4,703.0	184.0	89.0	383.0	19.0	20.0	13.0	39.0	8.0	7.0	39.0	7.0	58.0
1984	76.0	258.0	3,633.0	141.0	71.0	325.0	17.0	18.0	12.0	35.0	7.0	6.0	38.0	68.0
1985	196.0	59.0	199.0	2,713.0	102.0	51.0	243.0	13.0	14.0	9.0	28.0	6.0	5.0	95.0
1986	6,110.0	152.0	44.0	135.0	1,598.0	55.0	28.0	139.0	7.0	8.0	5.0	17.0	3.0	65.0
1987	102.0	4,760.0	116.0	32.0	93.0	1,116.0	40.0	21.0	106.0	5.0	6.0	4.0	14.0	63.0
1988	252.0	79.0	3,566.0	79.0	19.0	51.0	623.0	23.0	12.0	63.0	3.0	4.0	3.0	56.0
1989	903.0	197.0	60.0	2,571.0	53.0	12.0	33.0	417.0	15.0	8.0	42.0	2.0	3.0	50.0
					Canadian management zone									
1977	0.0	1.0	17.0	11.0	22.0	196.0	42.0	34.0	23.0	19.0	14.0	2.0	26.0	99.0
1978	0.0	1.0	5.0	47.0	22.0	29.0	186.0	34.0	26.0	17.0	14.0	11.0	2.0	105.0
1979	0.0	1.0	6.0	12.0	81.0	26.0	26.0	148.0	26.0	20.0	13.0	11.0	9.0	88.0
1980	0.0	4.0	1.0	4.0	7.0	43.0	13.0	13.0	72.0	13.0	9.0	6.0	6.0	54.0
1981	0.0	0.0	20.0	3.0	11.0	13.0	52.0	12.0	11.0	60.0	10.0	8.0	6.0	54.0
1982	0.0	6.0	14.0	195.0	19.0	27.0	20.0	61.0	13.0	11.0	61.0	11.0	9.0	72.0
1983	0.0	202.0	29.0	37.0	297.0	20.0	23.0	16.0	48.0	10.0	8.0	49.0	9.0	71.0
1984	0.0	2.0	142.0	16.0	19.0	152.0	10.0	11.0	8.0	24.0	5.0	4.0	26.0	46.0
1985	0.0	0.0	2.0	125.0	12.0	12.0	87.0	5.0	6.0	4.0	12.0	2.0	2.0	43.0
1986	0.0	1.0	2.0	19.0	526.0	29.0	18.0	100.0	5.0	6.0	4.0	12.0	2.0	49.0
1987	0.0	22.0	2.0	1.0	14.0	332.0	16.0	10.0	53.0	3.0	3.0	2.0	7.0	32.0
1988	0.0	0.0	102.0	7.0	4.0	20.0	320.0	13.0	7.0	37.0	2.0	2.0	1.0	34.0
1989	0.0	0.0	0.0	124.0	6.0	3.0	12.0	179.0	7.0	3.0	19.0	1.0	1.0	23.0
					Total population									
1977	295.0	235.0	764.0	174.0	148.0	776.0	134.0	100.0	66.0	53.0	40.0	7.0	74.0	279.0
1978	180.0	230.0	181.0	563.0	122.0	103.0	542.0	94.0	70.0	46.0	38.0	30.0	5.0	278.0
1979	2,162.0	141.0	178.0	133.0	401.0	86.0	72.0	385.0	67.0	50.0	33.0	28.0	23.0	223.0
1980	285.0	1,689.0	108.0	129.0	91.0	270.0	58.0	50.0	264.0	46.0	34.0	23.0	21.0	194.0
1981	355.0	223.0	1,307.0	80.0	93.0	64.0	190.0	40.0	35.0	186.0	32.0	25.0	18.0	168.0
1982	6,258.0	277.0	170.0	951.0	55.0	62.0	42.0	126.0	27.0	22.0	124.0	22.0	18.0	146.0
1983	333.0	4,905.0	213.0	126.0	680.0	39.0	43.0	29.0	87.0	18.0	15.0	88.0	16.0	129.0
1984	76.0	260.0	3,775.0	157.0	90.0	477.0	27.0	29.0	20.0	59.0	12.0	10.0	64.0	114.0
1985	196.0	59.0	201.0	2,838.0	114.0	63.0	330.0	18.0	20.0	13.0	40.0	8.0	7.0	138.0
1986	6,110.0	153.0	46.0	154.0	2,124.0	84.0	46.0	239.0	12.0	14.0	9.0	29.0	5.0	114.0
1987	102.0	4,782.0	118.0	33.0	107.0	1,448.0	56.0	31.0	159.0	8.0	9.0	6.0	21.0	95.0
1988	252.0	79.0	3,668.0	86.0	23.0	71.0	943.0	36.0	19.0	100.0	5.0	6.0	4.0	90.0
1989	903.0	197.0	60.0	2,695.0	59.0	15.0	45.0	596.0	22.0	11.0	61.0	3.0	4.0	73.0

Table 15 .--The implications of differing assumptions concerning the
selectivity of immature fish to the triennial assessment surveys
in the U.S. zone. (A = selectivity is fixed at 1.0 for all ages;
B = selectivity of age-2 fish estimated, selectivity fixed at 1.0
for all other ages; C = selectivity estimated for ages 2-3,
selectivity fixed at 1.0 for all other ages; D = selectivity
estimated for ages 2-4, selectivity fixed at 1.0 for all other
ages)

	A	B	C	D
Selectivity to U.S. survey				
Age 2	1.0	0.47	0.46	0.45
Age 3	1.0	1.00	0.74	0.73
Age 4	1.0	1.00	1.00	0.77
Ages 5-15	1.0	1.00	1.00	1.00
Recruitment (Billions of fish)				
1977 year class	2.059	2.066	2.177	2.190
1980 year class	5.844	5.972	6.272	6.321
1984 year class	5.082	5.986	6.090	6.126
1987 year class	0.433	0.872	0.868	0.903
1989 Biomass (million t)	1.676	1.924	2.018	2.040
Log(likelihood)	-706.05	-650.48	-631.22	-626.45

Table 16. - -Effect of changing the emphasis on the log(likelihood) for Pacific whiting survey biomass. All other runs of the model were made with the emphasis set at 5.0. Less negative values of the log(likelihood) indicate a better fit to that type of data. The headings "U.S. survey" and "Canadian survey" refer to the NMFS triennial survey data from the U.S. and Canadian zones, respectively.

Emphasis	0.1	1.0	5.0	10.0	25.0	100.0
Numbers at age 2 by year class						
1977	2.978	2.383	2.162	2.173	2.219	2.374
1980	8.000	6.585	6.258	6.225	6.095	5.512
1984	4.920	5.310	6.110	6.262	6.461	6.696
1987	0.931	0.774	0.903	0.920	0.883	0.836
Log(likelihood) components						
U.S. fish. age	-169.1	-186.0	-210.5	-214.1	-221.1	-249.4
Can. fish. age	-238.6	-234.7	-231.2	-231.3	-233.0	-250.3
U.S. survey age	-130.7	-154.7	-186.0	-194.6	-205.4	-232.5
Can. survey age	-61.5	-58.9	-61.5	-62.7	-63.5	-68.0
U.S. surv. biom.	-78.0	-17.4	5.5	7.3	8.7	10.0
Can. surv. biom.	-19.5	3.4	6.1	6.1	6.1	6.3
Age 2+ biomass (million t) in 1990*	2.107	1.892	2.018	2.055	2.091	2.082

*Biomass of ages 2 and older at the beginning of 1990.

Table 17 .--Selectivity at age used in reconstructing the historical
recruitment and abundance of Pacific whiting. For all data
sources except the NMFS triennial survey data from the U.S. and
Canadian zones, a double logistic curve was used to model
selectivity. For the NMFS triennial survey data from the U.S.
zone, selectivity was fixed at 1.0 except for ages 2 and 3 where
individual selectivity coefficients were estimated. For the NMFS
triennial survey data from the Canadian zone, only the descending
limb of the selectivity curve was modeled using a logistic
function. The headings "U.S. survey" and "Canadian survey" refer
to the NMFS triennial survey data from the U.S. and Canadian
zones, respectively.

Age (years)	U.S. fishery	1975 U.S. fishery	Dark (1975) age comps.	U.S. survey	Canadian fishery	Canadian survey
2	0.04	0.19	0.00	0.45	0.00	1.00
3	0.15	0.25	0.00	0.74	0.51	1.00
4	0.42	0.32	0.01	1.00	0.56	1.00
5	0.73	0.41	0.10	1.00	0.61	1.00
6	0.92	0.52	0.42	1.00	0.67	1.00
7	0.98	0.66	0.83	1.00	0.74	0.99
8	1.00	0.84	0.97	1.00	0.80	0.99
9	0.99	1.00	0.99	1.00	0.88	0.99
10	0.97	0.95	0.99	1.00	0.95	0.99
11	0.86	0.53	1.00	1.00	1.00	0.99
12	0.58	0.18	1.00	1.00	0.94	0.91
13	0.24	0.04	1.00	1.00	0.68	0.46
14	0.06	0.01	1.00	1.00	0.32	0.06
15	0.01	0.00	1.00	1.00	0.10	0.00

Table 18. - Time series of biomass and fishing mortality for Pacific whiting as estimated by a geographic version of the stock synthesis model. U.S. and Canadian fishing mortality rates are annual rates relative to the portion of the stock in their respective national zones. Biomass is in millions of metric tons of age-2 and older fish, and is presented for the beginning of the year and as the mean within the year. Recruitment is presented as billions of age-2 fish at the beginning of the year.

Year	Beginning biomass	Mean biomass	Beginning spawning biomass	Recruitment (billions)	U.S. fish. mortality	Can. fish. mortality
1958	3.061	2.947	1.398	0.110	0.000	0.000
1959	2.799	2.636	1.335	0.134	0.000	0.000
1960	2.474	2.307	1.216	0.104	0.000	0.000
1961	2.190	2.039	1.054	0.360	0.000	0.000
1962	2.045	1.939	0.920	0.923	0.015	0.002
1963	2.406	2.445	0.847	3.502	0.017	0.002
1964	2.632	2.702	1.003	0.604	0.015	0.002
1965	2.808	2.771	1.143	1.028	0.011	0.003
1966	2.929	2.824	1.260	1.404	0.130	0.003
1967	2.848	2.689	1.214	0.982	0.179	0.133
1968	2.690	2.585	1.134	1.167	0.064	0.228
1969	2.677	2.556	1.118	1.323	0.091	0.341
1970	2.578	2.431	1.084	0.910	0.175	0.252
1971	2.374	2.250	1.017	0.752	0.145	0.092
1972	2.732	2.745	0.966	3.923	0.082	0.152
1973	2.887	2.888	1.125	0.423	0.158	0.050
1974	2.808	2.633	1.193	0.403	0.188	0.057
1975	2.635	2.463	1.169	1.316	0.276	0.052
1976	2.331	2.135	1.047	0.275	0.256	0.019
1977	1.954	1.797	0.888	0.295	0.169	0.012
1978	1.572	1.368	0.743	0.180	0.149	0.026
1979	1.643	1.640	0.628	2.162	0.204	0.050
1980	1.666	1.657	0.657	0.285	0.131	0.084
1981	1.584	1.446	0.659	0.355	0.203	0.132
1982	2.257	2.353	0.613	6.258	0.120	0.228
1983	2.309	2.205	0.796	0.333	0.111	0.349
1984	2.204	2.147	0.902	0.076	0.103	0.295
1985	2.135	2.071	1.030	0.196	0.070	0.119
1986	3.117	2.920	0.883	6.110	0.151	0.236
1987	2.824	2.670	1.013	0.102	0.176	0.301
1988	2.508	2.283	1.029	0.252	0.154	0.426
1989	2.238	1.993	0.994	0.903	0.221	0.413
Avg. 1960-89	2.402	2.298	0.978	1.230	0.125	0.135

Table 19.- -Modeling the effect of discard on estimated recruitment and biomass using the stock synthesis model. Percent discard is determined relative to the total yield in biomass from a fishery. The level of discard in the U.S. and Canadian fisheries for Pacific whiting was assumed to be equal for this analysis. Mean age-2 recruitment is in billions of fish, age 2+ biomass is in millions of metric tons.

	Level of discard			
	0.0%	5.0%	10.0%	20.0%
Total log(likelihood)	-631.2	-637.1	-643.8	-658.2
Mean 1977-89 age 2 recruitment	1.347	1.365	1.399	1.444
Age 2+ biomass at the beginning of 1990	2.018	2.009	2.036	2.038

Table 20.--Parameter values for the revised age-structured simulation model used to estimate long-term Pacific whiting yield.

Age	2	3	4	5	6	7	8	9	10	11	12	13	14	15
USWT	0.280	0.398	0.488	0.566	0.621	0.669	0.720	0.765	0.806	0.863	0.924	0.974	0.992	1.065
CANWT	0.294	0.493	0.603	0.679	0.748	0.788	0.851	0.886	0.915	0.984	1.045	1.090	1.123	1.192
POPWT	0.256	0.388	0.491	0.584	0.651	0.712	0.771	0.827	0.873	0.924	0.976	1.028	1.075	1.117
USSLCT	0.040	0.150	0.420	0.730	0.920	0.980	1.000	0.990	0.970	0.860	0.580	0.240	0.060	0.010
CANSLCT	0.000	0.510	0.560	0.610	0.670	0.740	0.800	0.880	0.950	1.000	0.940	0.680	0.320	0.100
MATURE	0.000	0.500	0.750	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
PROPFEM	0.480	0.501	0.512	0.520	0.524	0.526	0.529	0.536	0.539	0.544	0.553	0.561	0.568	0.575
USCAN	0.000	0.009	0.033	0.087	0.175	0.268	0.329	0.358	0.369	0.373	0.375	0.376	0.376	0.376
POPINIT	0.903	0.197	0.060	2.695	0.059	0.015	0.045	0.596	0.022	0.011	0.061	0.003	0.004	0.073
NMORT	0.237	0.237	0.237	0.237	0.237	0.237	0.237	0.237	0.237	0.237	0.237	0.237	0.237	0.237

USWT   = United States fishery weight at age (g).
CANWT   = Canadian fisher weight at age (g).
POPWT   = Population weight at age (g).
USSLCT   = U.S. fishery selectivity at age.
CANSLCT = Canadian fishery selectivity at age.
MATURE   = Proportion of sexually mature females.
PROPFEM = Proportion by weight of females in the population.
USCAN   = Proportion of fish migrating into Canadian zone.
POPINIT = Initial population vector (billions).
NMORT   = Natural mortality rate.

Table 21.- -Sustainable yield for different management strategies estimated by averaging the results of 20 replicate simulations of the Pacific whiting fishery of 1,000 years each using the revised age-structured simulation model. SB_{opt} used in the variable F and hybrid algorithms is defined as the mean female spawning biomass level at a constant F strategy where the probability is 0.20 that the female spawning biomass goes below the cautionary level of female spawning biomass (SB_{caut}) of 457,000 metric tons. The average of the annual F values, reported for the variable and hybrid F strategies, is not equal to F_{opt} because spawning biomass is more frequently below SB_{opt} than above it. Yield and biomass are reported in 1,000 t (kt).

	F_{opt}	Total yield (kt)	CV	SB_{opt}	Mean F	Spawn. biom. (kt)	CV	% of prist. spawn. biomass	% years below SB_{caut}
Constant F strategy									
Low risk	0.17	168	47.2	---	---	889	44.4	61.8	10.3
Mod. risk	0.24	205	48.0	---	---	782	46.7	54.4	19.8
High risk	0.31	227	49.2	---	---	687	48.9	47.8	30.3
35% prist. spawn. biom.	0.58	278	56.0	---	---	503	57.6	35.0	54.2
Variable F strategy									
Low risk	0.21	202	74.4	782	0.211	785	38.7	54.6	10.6
Mod. risk	0.31	226	74.1	782	0.274	691	39.9	48.1	20.9
High risk	0.41	247	74.7	782	0.334	637	41.1	44.3	29.7
35% prist. spawn. biom.	0.80	278	77.0	782	0.514	503	44.1	35.0	54.2
Hybrid strategy									
Low risk	0.22	187	54.8	782	0.189	843	41.8	58.6	9.4
Mod. risk	0.33	221	61.2	782	0.261	728	44.6	50.6	20.3
High risk	0.42	235	64.2	782	0.312	655	44.9	45.6	30.6
35% prist. spawn. biom.	0.82	276	71.8	782	0.507	508	46.4	35.3	54.7

F_{opt} = level of fishing mortality required to achieve the stated management objective.

CV = coefficient of variation.

Table 22. --Summary of information used for the short-term yield forecasts of the Pacific whiting resource.

I. Beginning of the year population abundance (billions of fish) by age

Year/Age	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1989	0.903	0.197	0.060	2.695	0.059	0.015	0.045	0.596	0.022	0.011	0.061	0.003	0.004	0.073
1990	1.230	0.707	0.150	0.043	1.811	0.038	0.009	0.028	0.359	0.013	0.007	0.039	0.002	0.060
1991	---	0.961	0.537	0.107	0.029	1.149	0.024	0.006	0.017	0.219	0.008	0.004	0.027	0.048

II. Current weight at age (kg)

Year/Age	2	3	4	5	6	7	8	9	10	11	12	13	14	15
U.S.	0.277	0.370	0.443	0.497	0.540	0.558	0.596	0.633	0.668	0.716	0.796	0.852	0.893	0.928
Canada	0.272	0.573	0.592	0.580	0.677	0.664	0.757	0.811	0.825	0.896	0.993	1.030	1.211	1.226
Popul.	0.284	0.379	0.457	0.520	0.568	0.594	0.633	0.677	0.718	0.757	0.815	0.892	0.972	1.048

1989 estimated yield: U.S.-211,000 t   Canada-98,000 t
1990 expected yield: U.S.-196,000 t   Canada-73,500 t

1990 beginning of year spawning biomass: 873,000 t
1991 beginning of year spawning biomass: 739,000 t

t = metric tons.

Table 23. --Summary of the 1991-93 potential annual yields. Yield and biomass
projections are in thousands of tons. Recruitment scenarios are
described in Item VII.

I. Hybrid, low-risk strategy   II. Constant F, low-risk strategy
    ($F = 0.22$)   (F = 0.17)

Recruit. scenario	Year	Yield	Spawn. biomass	Age-2+ biomass	Recruit. scenario	Year	Yield	Spawn. biomass	Age-2+ biomass
A	1991	183	738	2,396	A	1991	152	738	2,427
	1992	183	889	2,072		1992	147	905	2,133
	1993	205	895	1,624		1993	168	927	1,713
B	1991	175	738	2,356	B	1991	146	738	2,385
	1992	145	649	2,167		1992	139	664	2,198
	1993	163	806	1,802		1993	131	822	1,858
C	1991	175	738	1,436	C	1991	146	738	1,464
	1992	138	649	2,127		1992	133	664	2,157
	1993	112	565	1,908		1993	123	581	1,923
D	1991	175	738	1,436	D	1991	146	738	1,464
	1992	138	649	1,206		1992	133	664	1,236
	1993	105	565	946		1993	116	581	961

III. Hybrid, moderate-risk   IV. Constant F, moderate-risk
      strategy (F = 0.33)   strategy (F = 0.24)

Recruit. scenario	Year	Yield	Spawn. biomass	Age-2+ biomass	Recruit. scenario	Year	Yield	Spawn. biomass	Age-2+ biomass
A	1991	265	738	2,317	A	1991	209	738	2,371
	1992	249	849	1,938		1992	195	876	2,039
	1993	272	827	1,445		1993	218	878	1,583
B	1991	253	738	2,282	B	1991	200	738	2,333
	1992	186	610	2,064		1992	183	637	2,110
	1993	208	751	1,669		1993	168	776	1,748
C	1991	253	738	1,361	C	1991	200	738	1,412
	1992	176	610	2,027		1992	174	637	2,072
	1993	135	512	1,802		1993	156	536	1,820
D	1991	253	738	1,361	D	1991	200	738	1,412
	1992	176	610	1,106		1992	174	637	1,151
	1993	125	512	843		1993	145	536	862

Table 23.- -Continued.

V. Hybrid, high-risk strategy (F = 0.42)					IV. Constant F, high-risk strategy (F = 0.31)				
Recruit. scenario	Year	Yield	Spawn. biomass	Age-2+ biomass	Recruit. scenario	Year	Yield	Spawn. biomass	Age-2+ biomass
A	1991	327	738	2,257	A	1991	264	738	2,318
	1992	295	819	1,842		1992	236	850	1,953
	1993	313	778	1,322		1993	260	834	1,469
B	1991	311	738	2,226	B	1991	252	738	2,283
	1992	210	581	1,993		1992	221	611	2,031
	1993	229	714	1,587		1993	198	735	1,652
C	1991	311	738	1,305	C	1991	252	738	1,362
	1992	197	581	1,958		1992	208	611	1,997
	1993	146	476	1,734		1993	181	496	1,733
D	1991	311	738	1,305	D	1991	252	738	1,362
	1992	197	581	1,037		1992	208	611	1,076
	1993	134	476	776		1993	168	496	778

VII. Recruitment scenarios

	Year class	Annual recruitment
A.	1989	strong
	1990	weak
	1991	weak
B.	1989	weak
	1990	strong
	1991	weak
C.	1989	weak
	1990	weak
	1991	strong
D.	1989	weak
	1990	weak
	1991	weak

Note: Strong - 3.526 billion (mean of top 25% historical recruitment)
Weak recruitment - 0.283 billion (mean of historical recruitment below median)
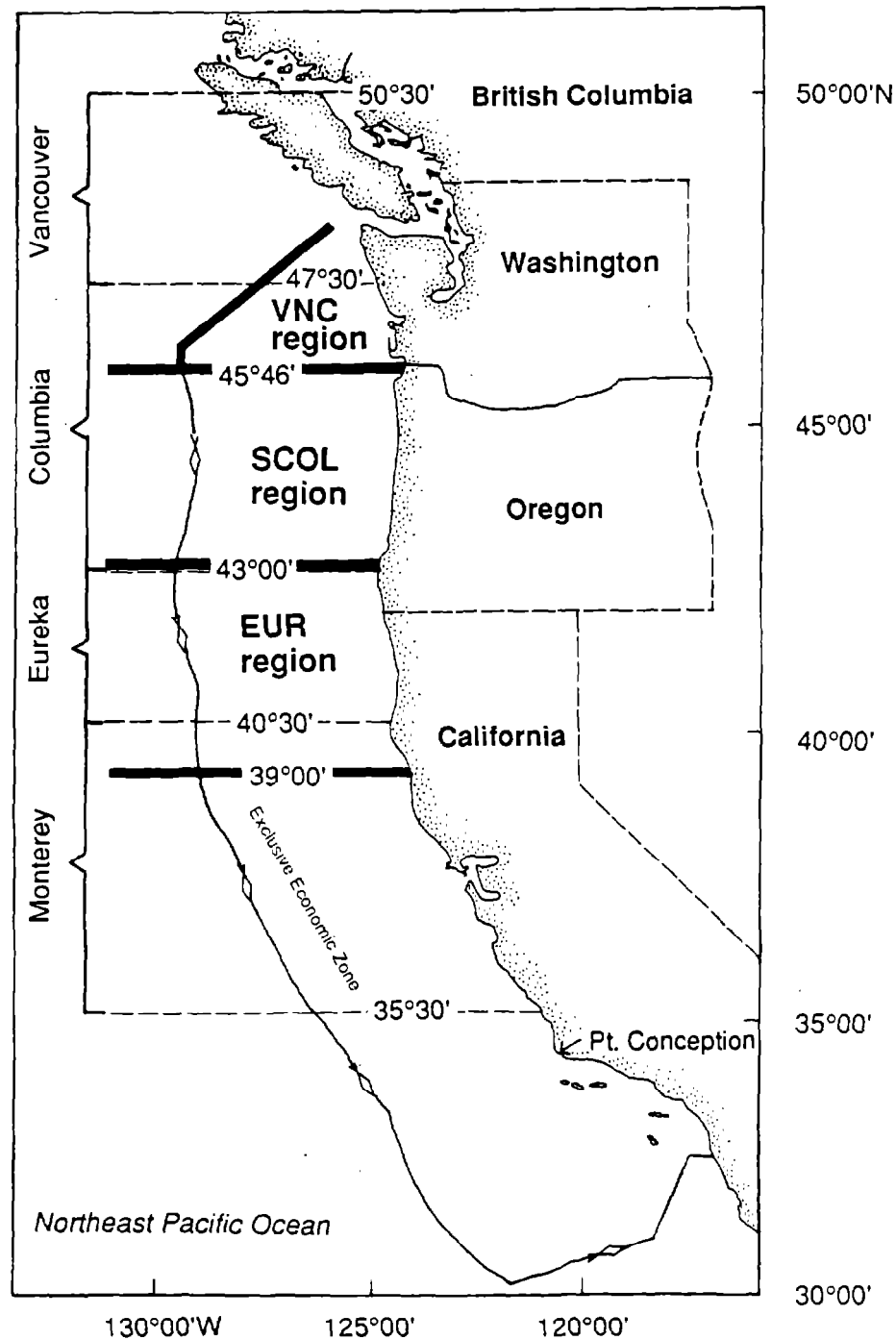
Figure 1. --Geographic regions along the west coast of the United States
defined as strata to estimate catch at age and length at age. EUR
region - lat. 39°00'N to lat. 43°00'N SCOL region - lat. 43°00'N
to lat. 45°46'N, VNC region - lat. 45°46'N to the U.S.-Canada
border.
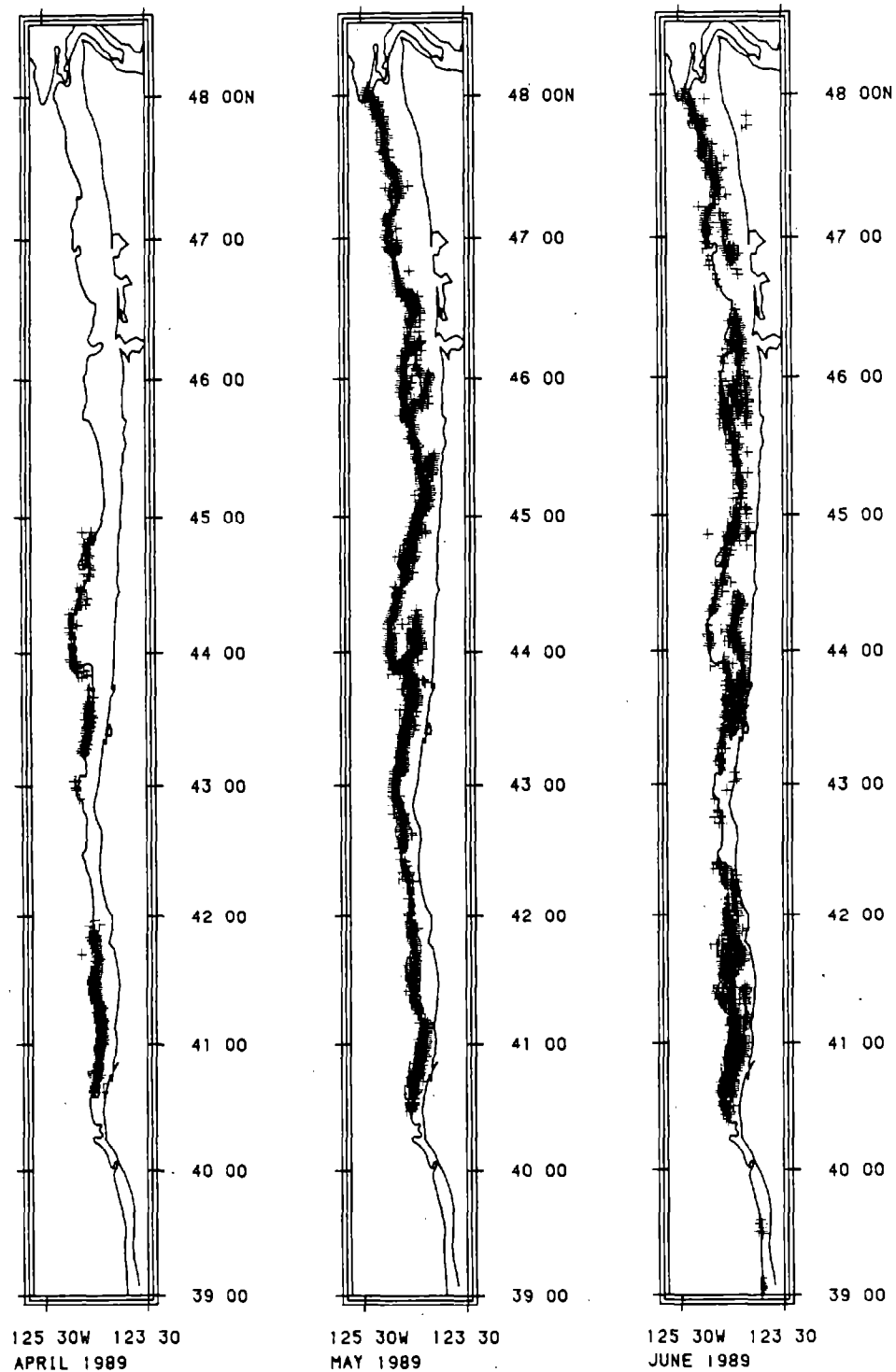
Figure 2.--Pacific whiting trawl position plots for April 1989 to June 1989 for the U.S. joint venture fishery. Each reported trawl position is marked by a "+". The black areas of the plots represent many overlapping trawl positions. A line is drawn at the shelf break at 200 meters.
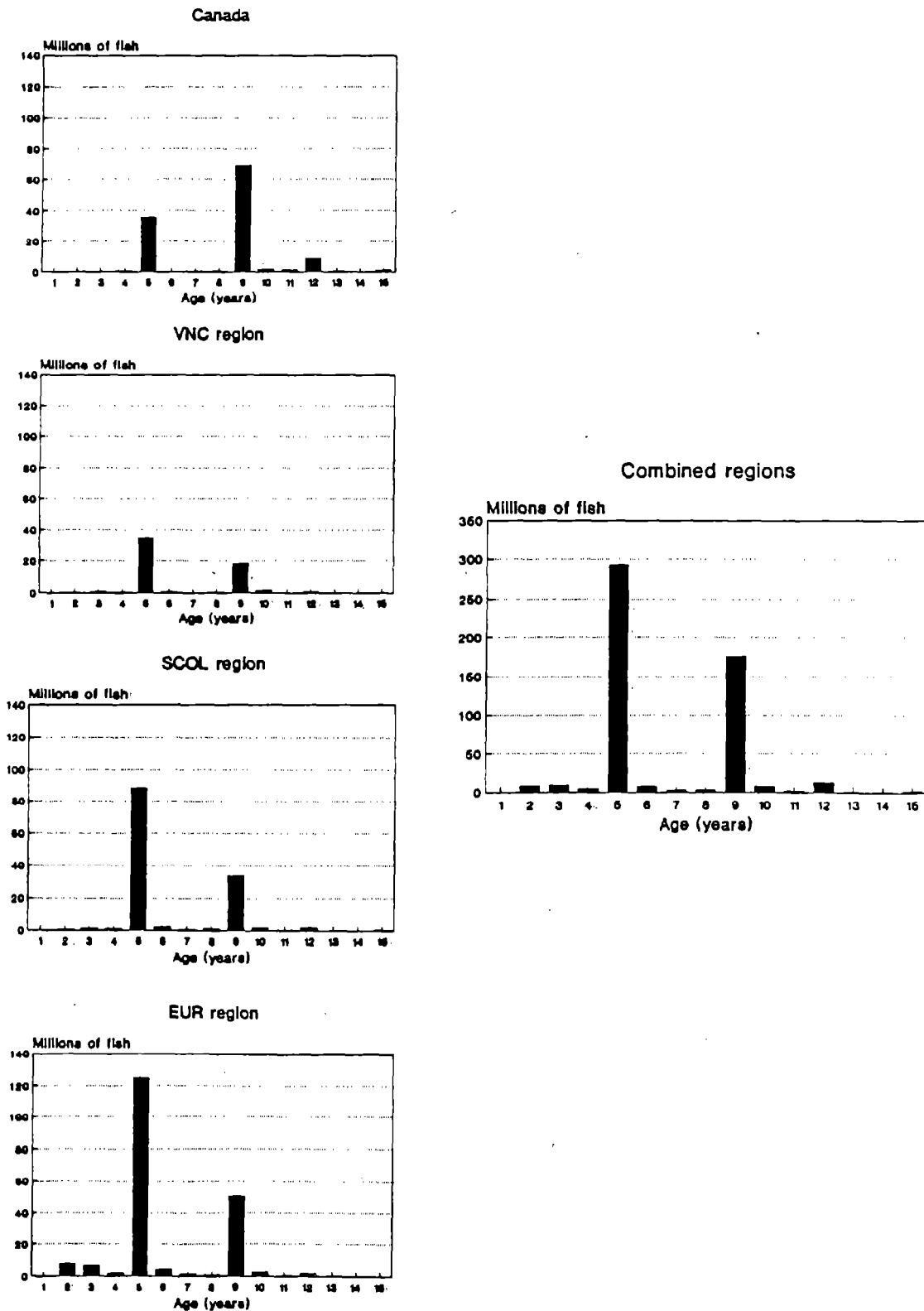
Figure 3.--Catch at age by geographic region in millions of fish for the 1989
Pacific whiting fishery. Sources: Jerald Berger, pers. commun.,
May 1990, and Mark Saunders, pers. commun., May 1990).
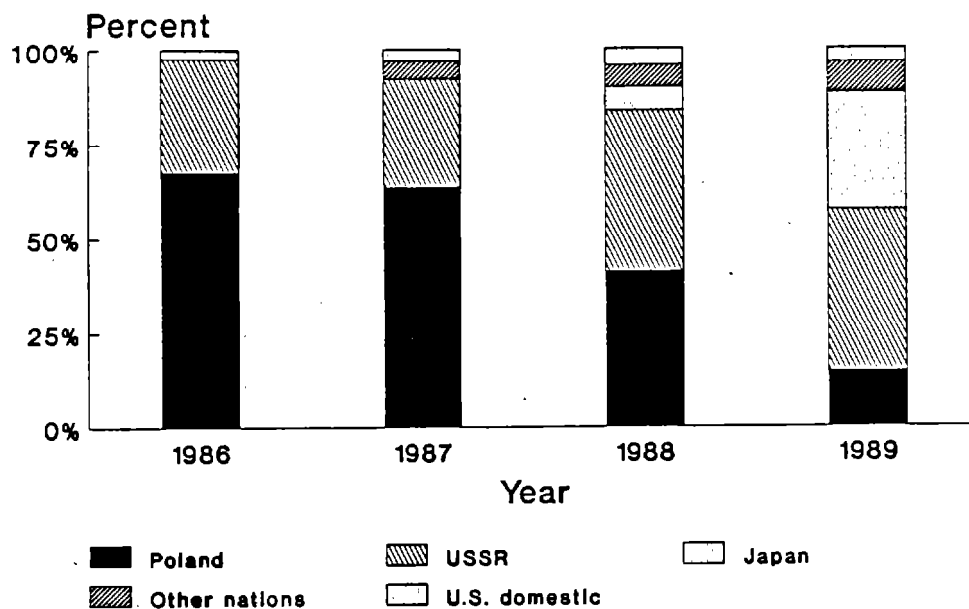
Figure 4. --Percent receipts of Pacific whiting by nationality, 1986-89.
Included are both foreign fishery catches and joint venture
deliveries.   Source: Jerald Berger, pers. commun., May 1990.

Males

Mean length (cm)

Age 10
Age 9
Age 8
Age 7
Age 6
Age 5
Age 4
Age 3

1978 1979 1980 1981 1982 1983 1984 1985 1986 1987 1988 1989

Year

Females

Mean length (cm)

Age 10
Age 9
Age 8
Age 7
Age 6
Age 5
Age 4
Age 3

1978 1979 1980 1981 1982 1983 1984 1985 1986 1987 1988 1989
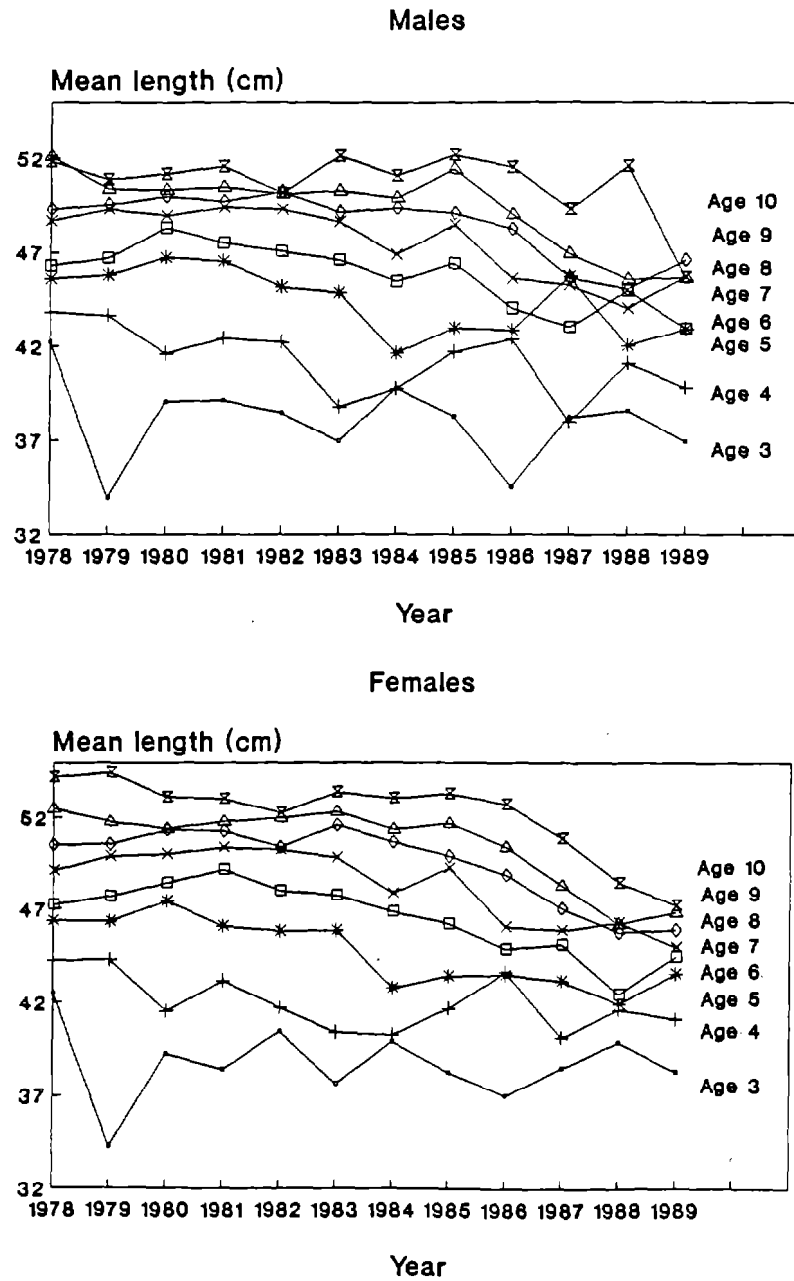
Year

Figure 5. --Mean U.S. fishery length at age for the months April-June (1978-89).

Males

Length (cm)

Age (years)

Females

Length (cm)

Age (years)
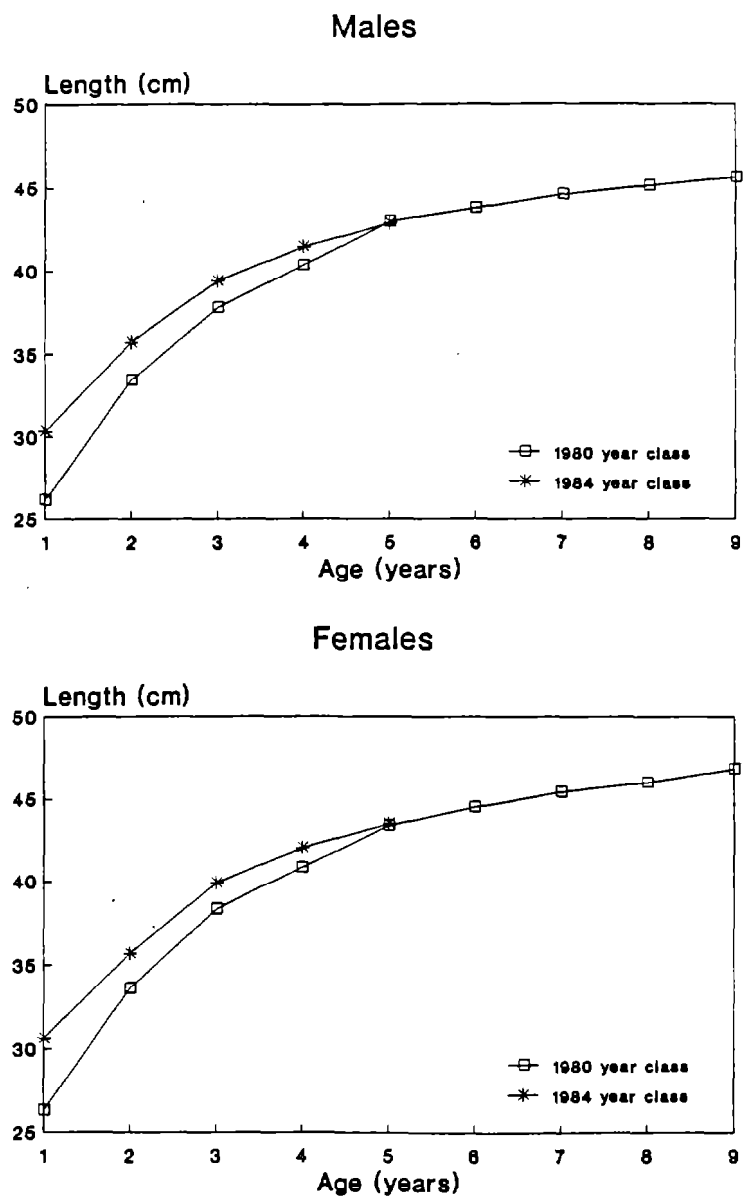
Figure 6. --A comparison of the growth trajectory of the 1980 and 1984 year classes. Length at age is the mean estimated from samples of the U.S. fishery for Pacific whiting.
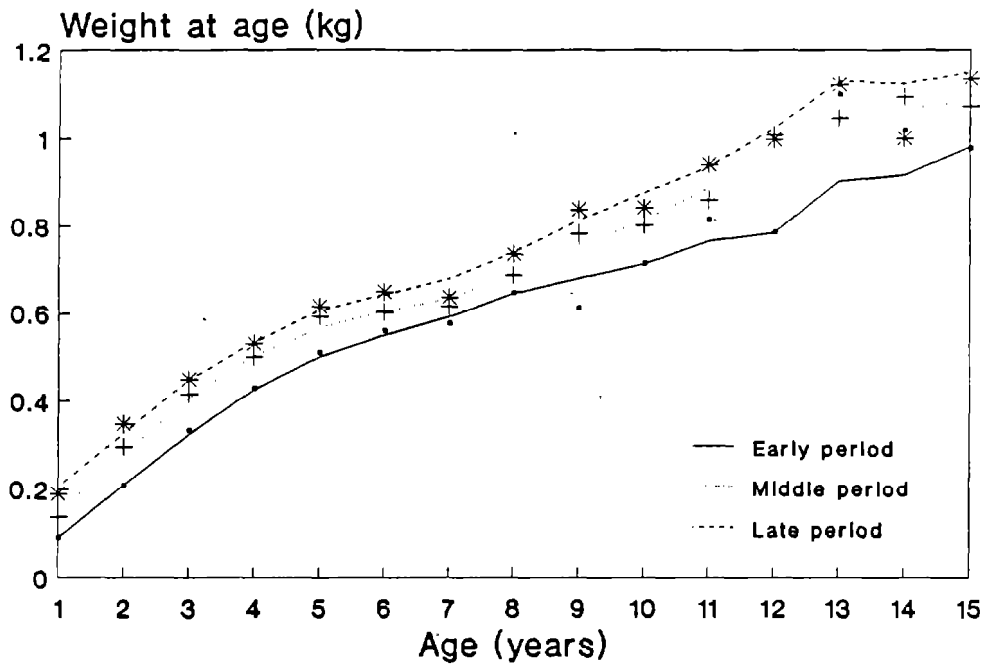
Figure 7. --Mean weight at age of Pacific whiting in the U.S. fishery for the early (April-June), middle (July-August), and late (September-October) time periods from 1978 to 1989.
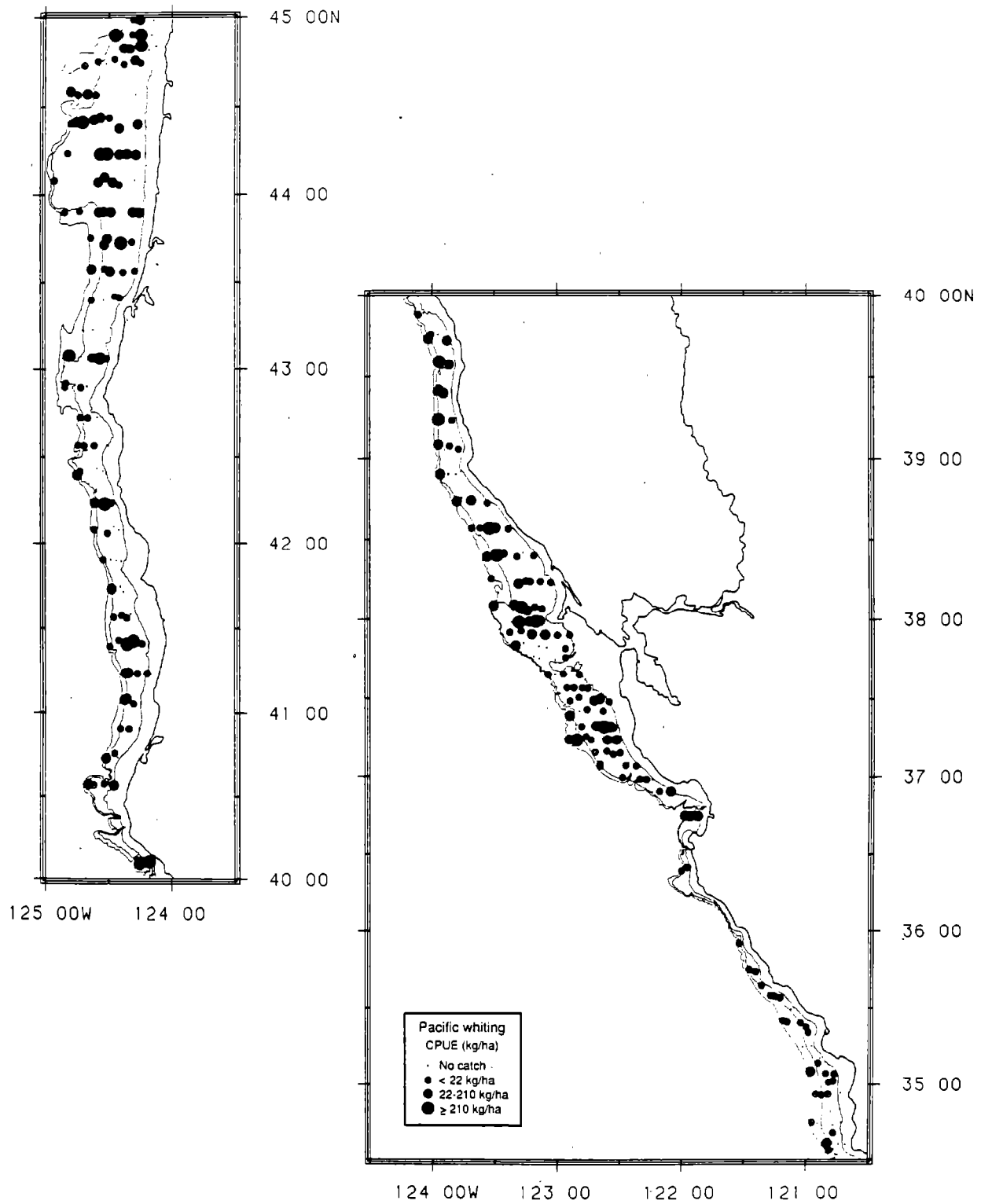
Figure 8. --The distribution of Pacific-whiting catch per unit effort (CPUE)
observations for the 1989 west coast bottom trawl survey.
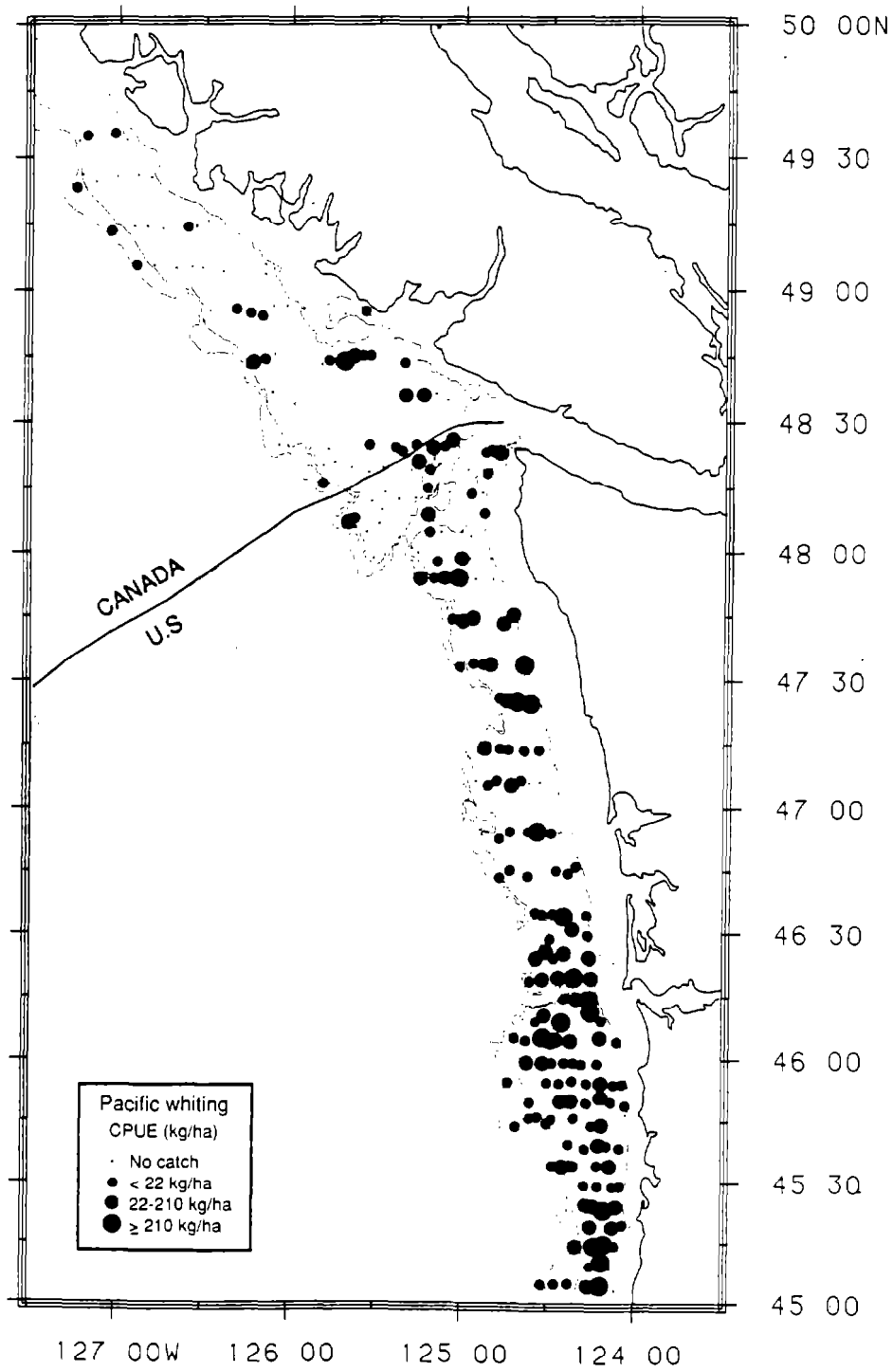
Figure 8. --Continued.
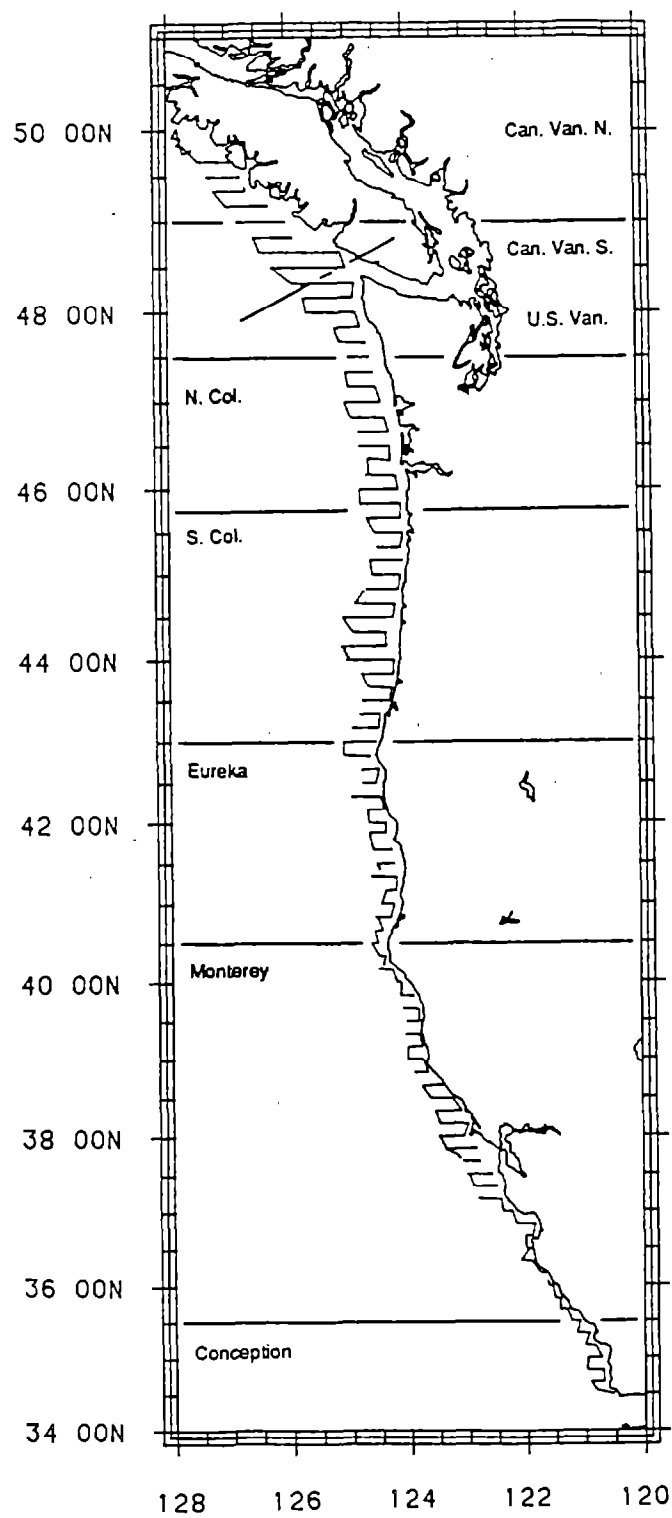
Figure 9.-- Location of transect lines and geographic summary areas for the 1989 west coast acoustic survey of Pacific whiting.
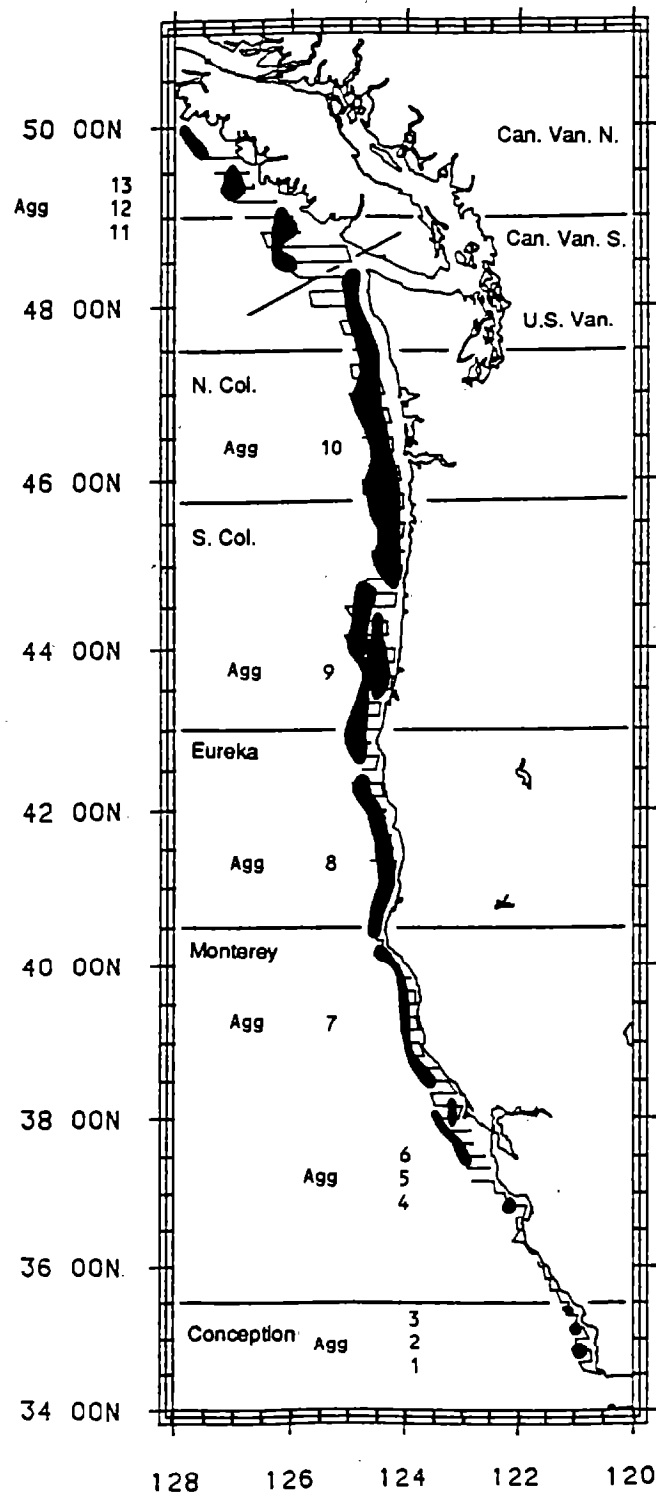
Figure 10. --Approximate locations of Pacific whiting aggregations encountered during the 1989 west coast acoustic survey.
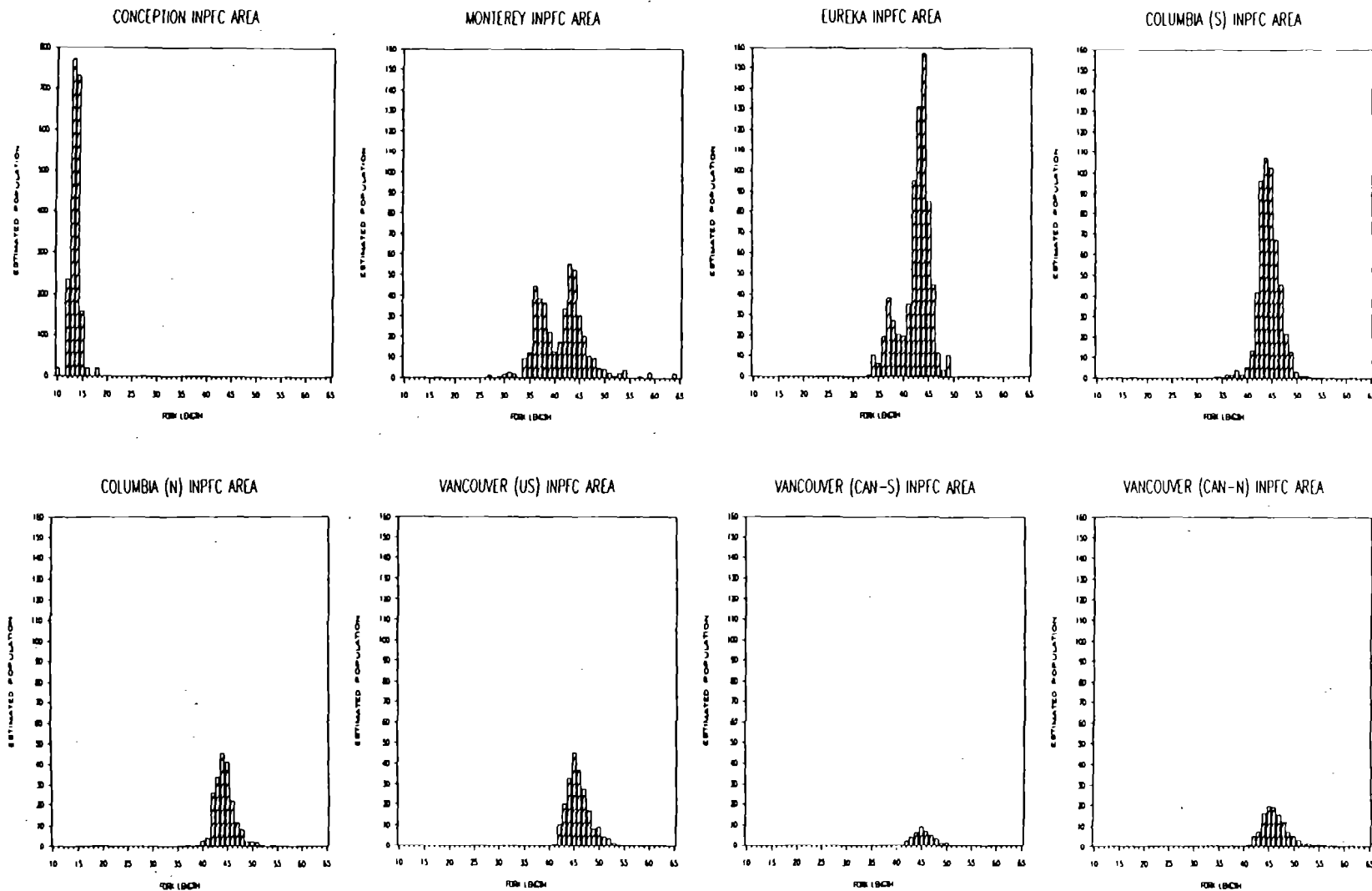
Figure 11.-- Estimated numbers (millions) at length of Pacific whiting by International North Pacific Fisheries
Commission (INPFC) region for 1989 west coast acoustic survey.
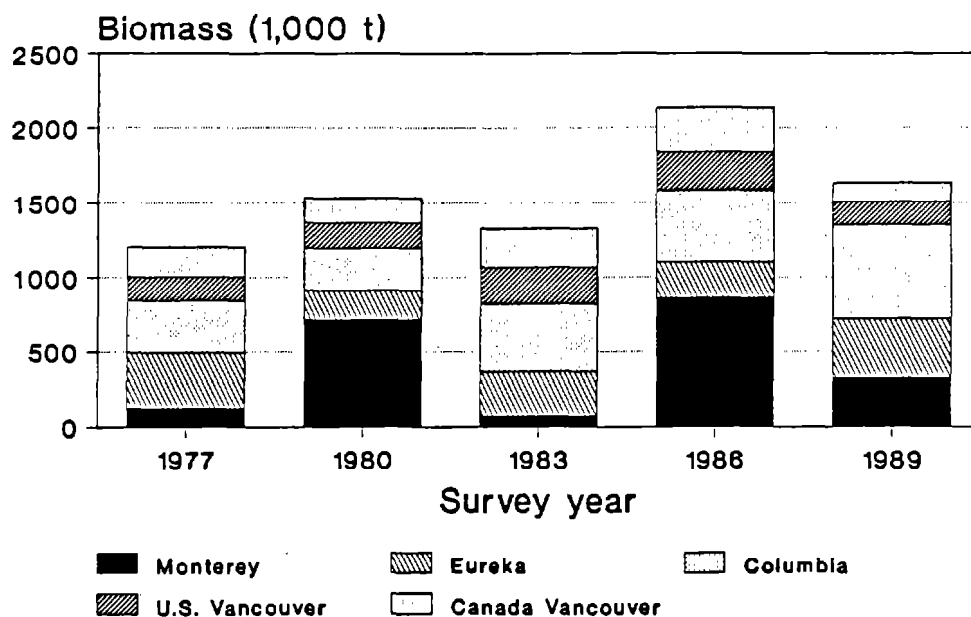
Figure 12. --Estimated biomass (metric tons, t) by region for the triennial
west coast assessment surveys in 1977, 1980, 1983, 1986, and 1989.
The estimates were obtained by summing the bottom trawl and
acoustic estimates. Sources: Dark et al. 1980, Weinberg et al,
1984, Nelson and Dark 1985, Coleman 1986, Coleman 1988, Neal
Williamson, pers. commun., May 1989
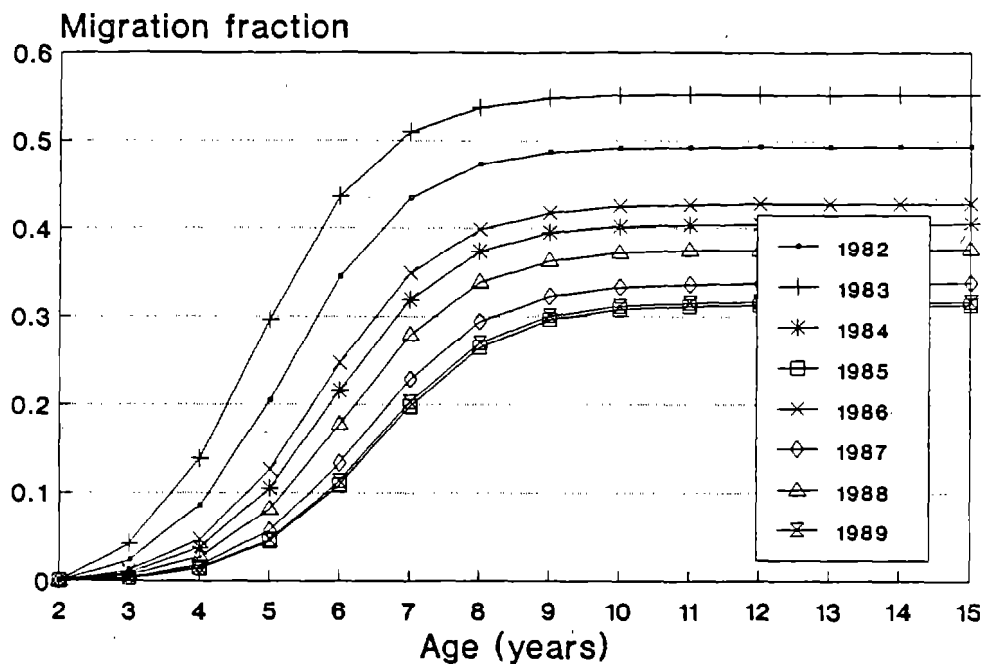
Figure 13. --Annual migration curves for 1982-89 estimated by a version of the stock synthesis model incorporating geographic structure. These curves represent the annual age-specific fraction of the population migrating into Canadian waters.
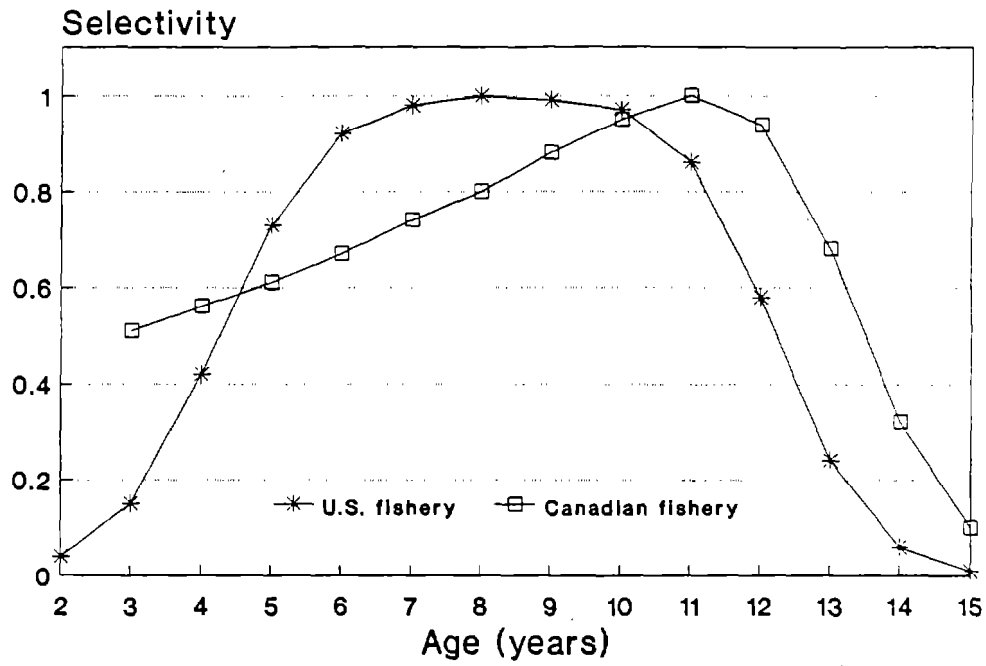
Selectivity

Figure 14. --Selectivity curves for the U.S. and Canadian fisheries estimated by the stock synthesis model.
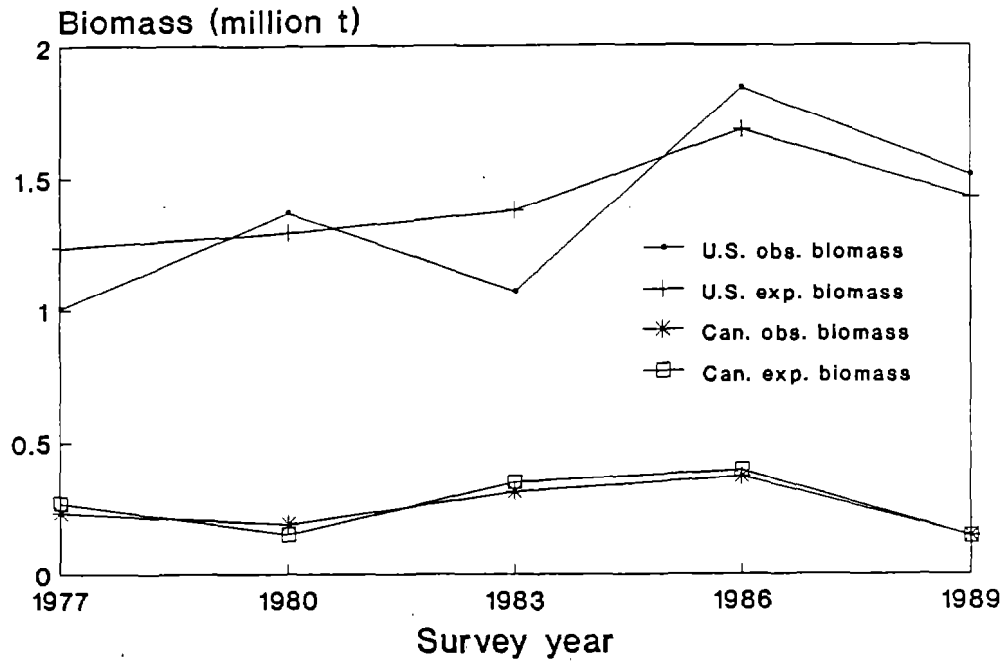
Figure 15.-- Fit to the triennial National Marine Fisheries Service assessment
surveys in U.S. and Canadian waters using a geographic stock
synthesis model. Observed (obs.) and expected (exp.) survey
biomass is expressed in millions of metric tons (t).
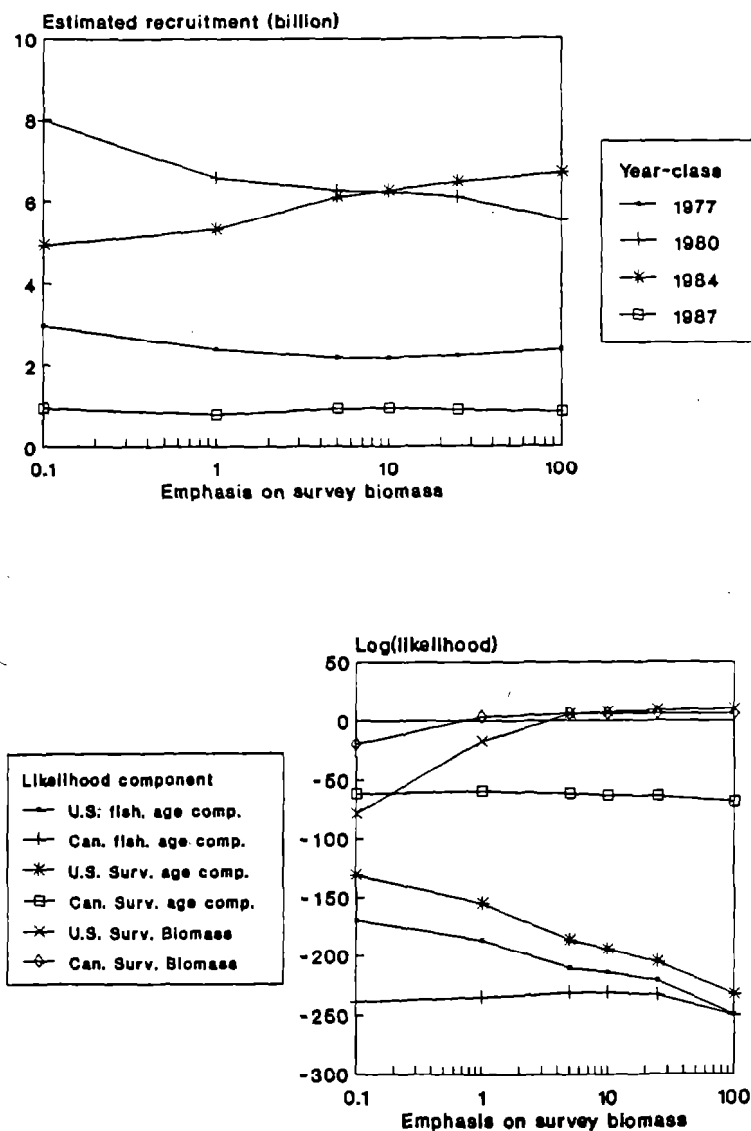
Figure 16. --The effect of changing the emphasis factor for the survey biomass
log(likelihood) on recruitment estimates for the Pacific whiting
year classes 1977, 1980, 1984, and 1987 (top panel), and on the
likelihood components for the different sources of information
used to fit the synthesis model (bottom panel). A less negative
value for an information source indicates a better fit of the
model to the data from that source. The headings "U.S. survey"
and "Canadian survey" refer to the NMFS triennial survey data from
the U.S. and Canadian zones, respectively.
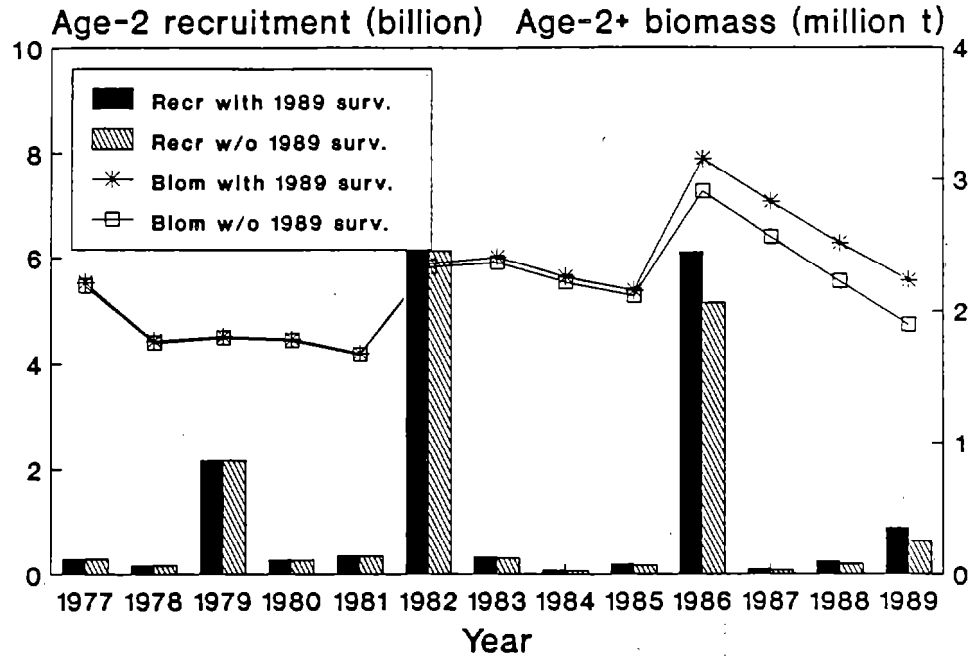
Figure 17. --A comparison of estimates of Pacific whiting recruitment and
population biomass (metric tons, t) for two estimation runs of the
stock synthesis model. In one run the 1989 survey biomass is
given the same weight as the other survey biomass observations.
In the other run the 1989 survey biomass was given no weight in
fitting the model.
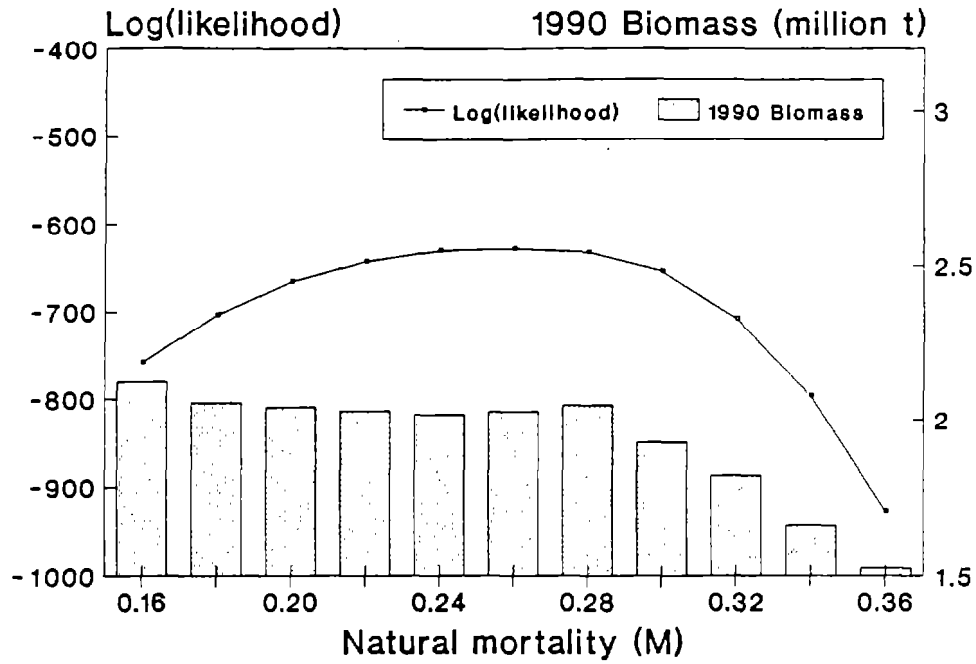
Figure 18. --The sensitivity of the model fit to the choice of a constant natural mortality rate, as measured by the overall log(likelihood). The log(likelihood) was maximum between 0.24 and 0.26. Estimated biomass for the start of 1990 is expressed in millions of metric tons (t).

Fishing mortality (F)
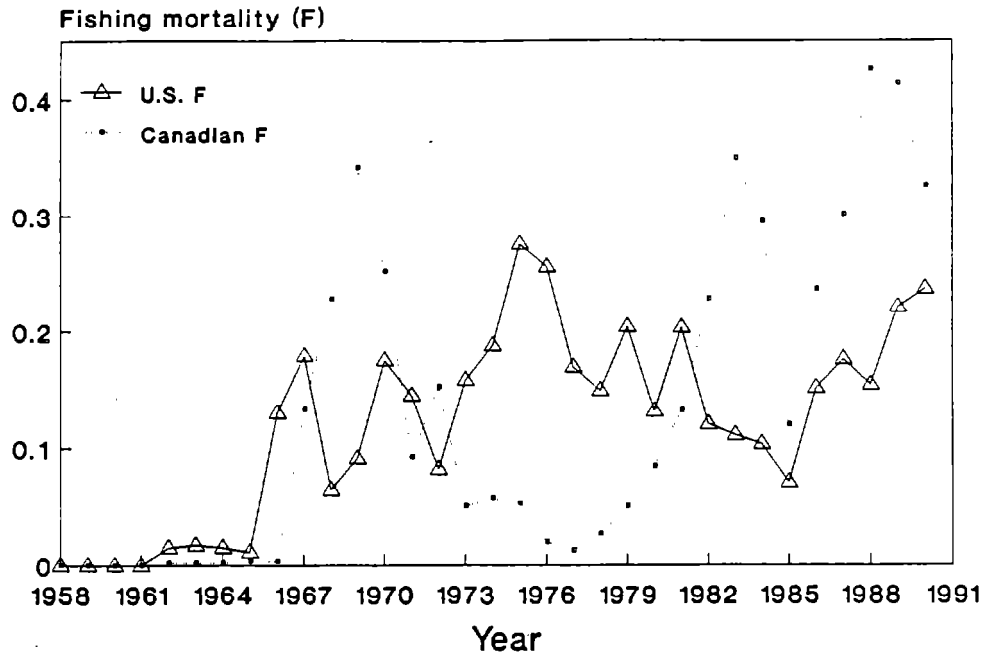
Figure 19.--Time trend of U.S. and Canadian full recruitment fishing mortality (F) for the coastal Pacific whiting population. Full recruitment occurs at age 8 in the U.S. fishery, and at age 11 in the Canadian fishery. The fishing mortalities are annual rates and apply to the portion of the stock that is in each national zone. A single mean migration curve was used to split the stock between U.S. and Canadian waters for all years.
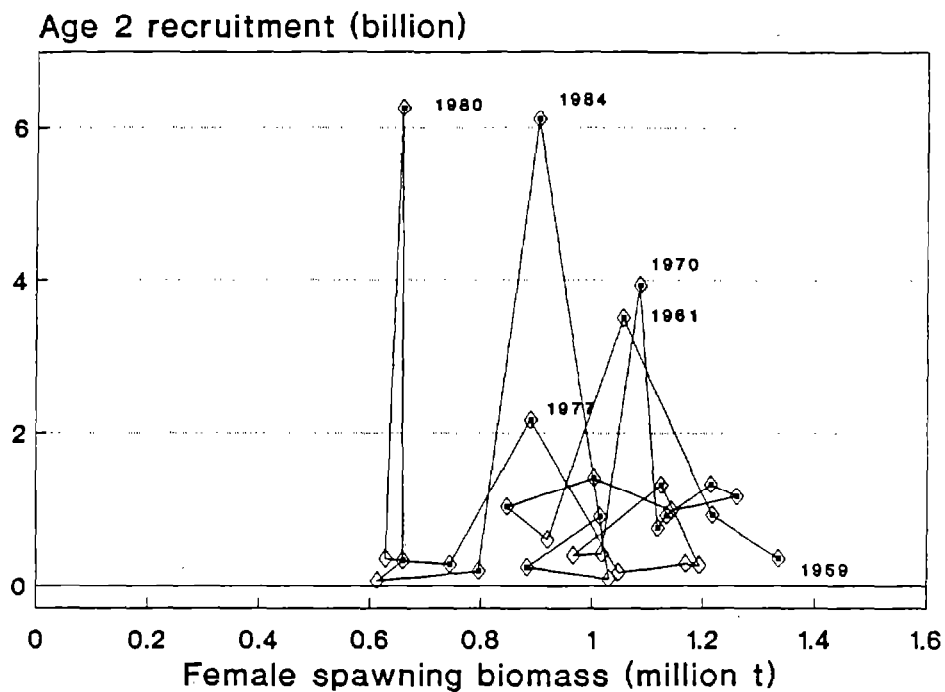
Figure 20.-- Female spawning biomass versus recruitment for Pacific whiting as estimated b the stock synthesis model. Dotted diamonds indicate warm (>15.0°C) years, the unfilled diamonds the cold (<15.0°C) years.
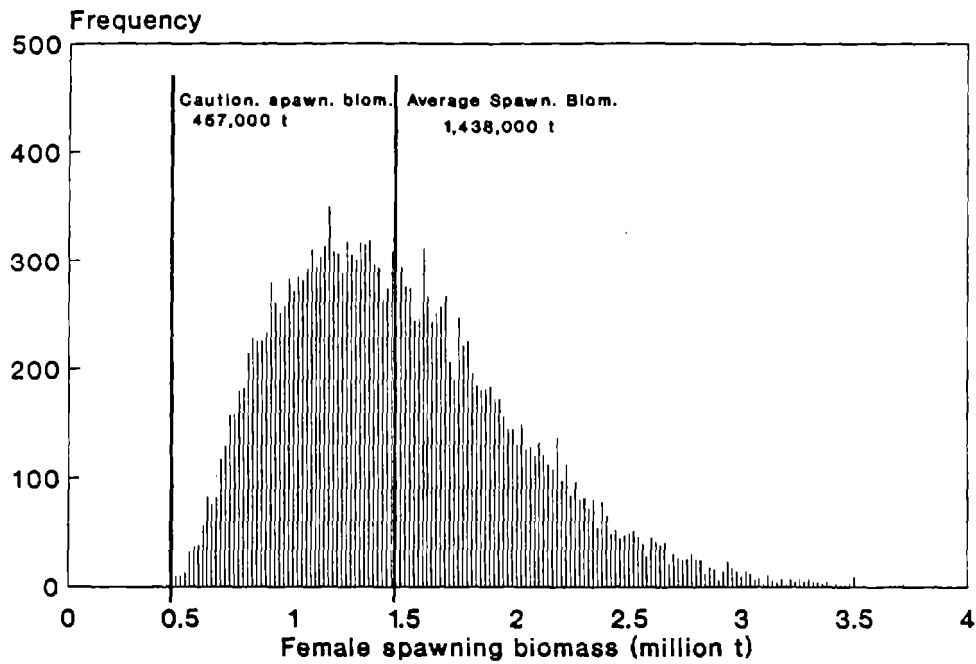
Figure 21.-- Frequency histogram of female spawning biomass (million metric
tons, t) resulting from 20 replicate 1,000 year simulations of an
unexploited Pacific whiting population. Recruitments to drive the
model were obtained by resampling from the observed recruitment
for 1958-87 year classes. A cautionary level of female spawning
biomass of 457,000 t was identified as the 0.1 percentile of the
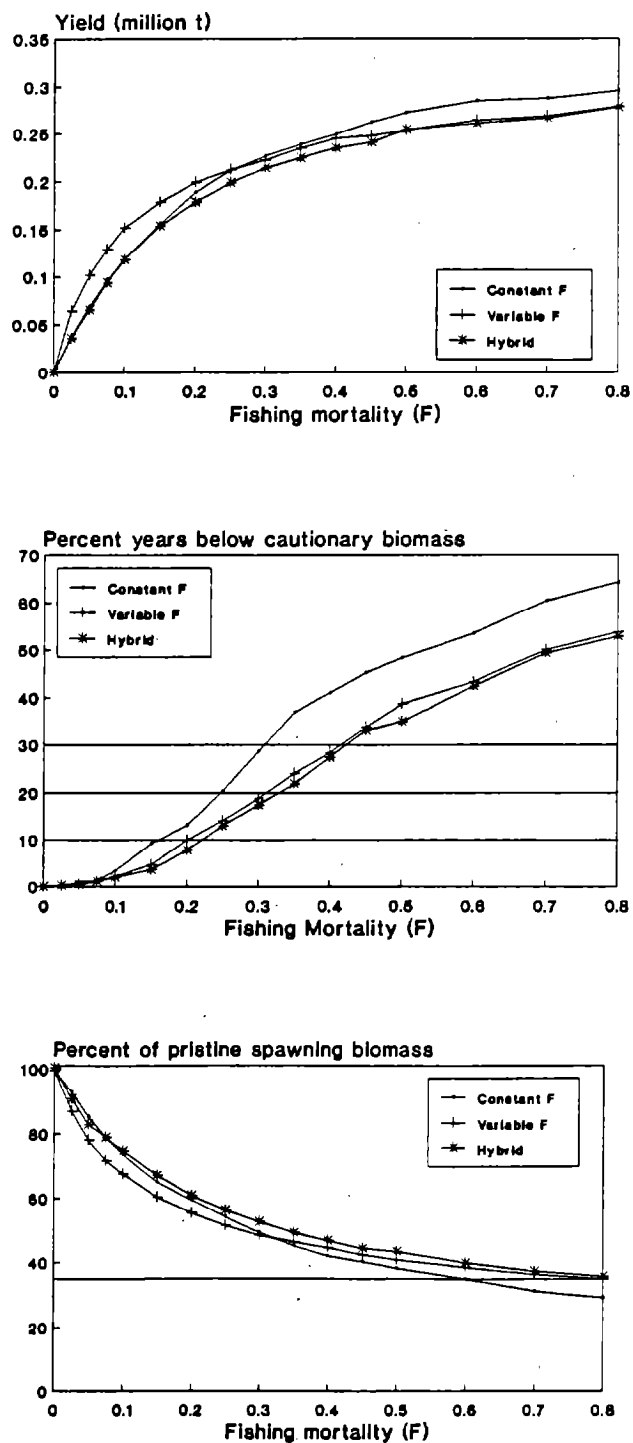empirical distribution of female spawning biomass for an
unexploited population.

Figure 22. --Comparison of the constant F strategy, the variable F strategy, and the hybrid strategy for managing the Pacific whiting fishery. Top panel, yield curves in millions of metric tons (t); middle panel, percent of years below a cautionary female spawning biomass of 457,000 t; and bottom panel, percent of pristine female spawning biomass.

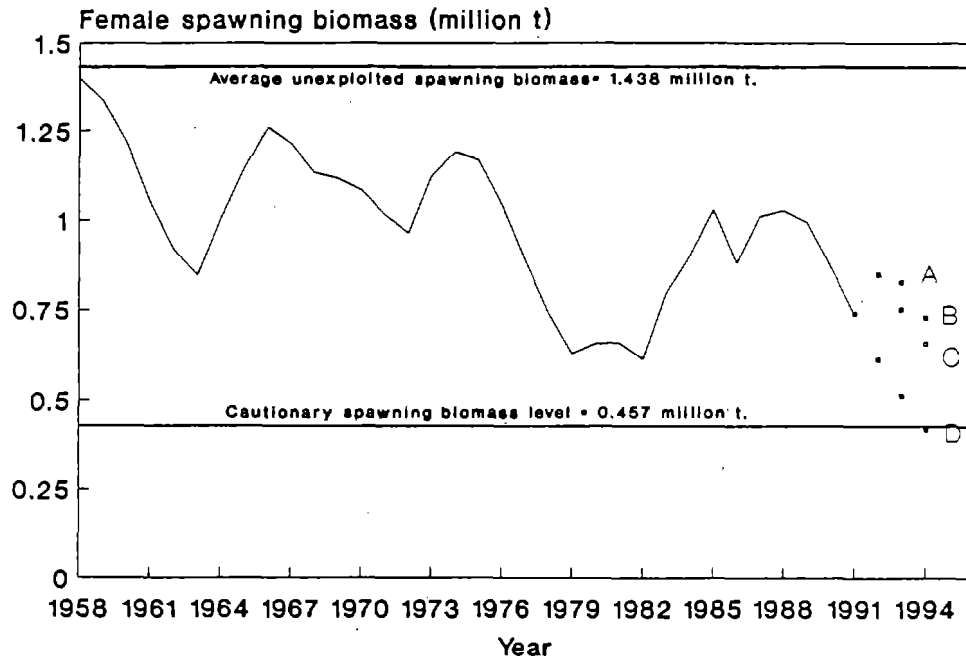**Female spawning biomass (million t)**

Figure 23. --Time trend of Pacific whiting female spawning biomass (million
metric tons, t) for 1958-91. The two horizontal lines in the
graph indicate the average unexploited female spawning biomass
level and the cautionary female spawning biomass level used in the
analysis to define risk. The average female spawning biomass from
1958 to 1990 was 0.892 million t. Trajectories A, B, C, and D
represent the projected female spawning biomass for 1991-94 with a
moderate risk hybrid harvesting strategy (F = 0.34) under
recruitment scenarios A, B, C, and D.   (See Table 23 for a
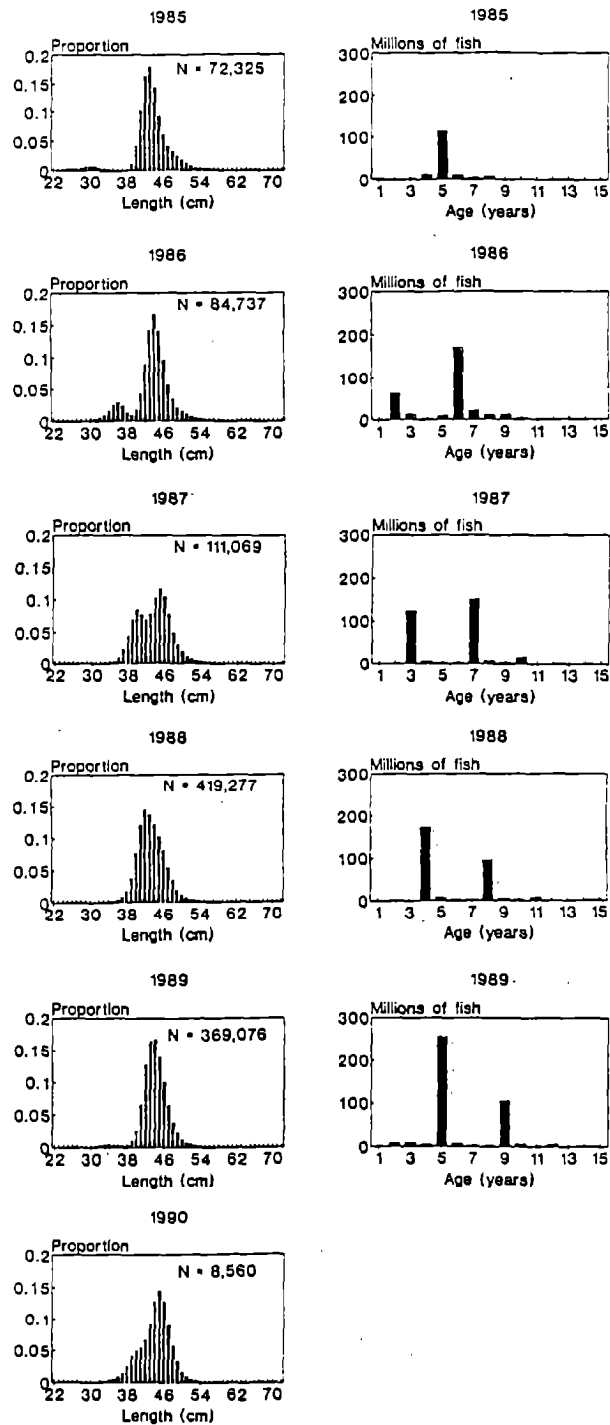description of the different recruitment scenarios.)

Figure 24.--Length frequency and catch at age of Pacific whiting in the U.S. management zone including the foreign, joint venture and domestic fisheries. The length-frequency histogram for 1990 is based on a preliminary tabulation of a small subsample of the available data. Source: Jerald Berger, pers. commun., May 1990.